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GENERAL MEETING, MAY 21ST, 1890.

SUBJECTS:

(Continued from Number 7.)

Life and Efficiency of Arc Light Carbons.
DISCUSSION.

Practical Aspects of the Alternating Current Theory.
DISCUSSION.

Note on a New Photometer.
DR. EDWARD L. NICHOLS.

The Limitations of Steam and Electric Transportation.
BY OSCAR T. CROSBY,

Automatic Electric Welding Machines.
BY HERRMANN LEMP, JR.

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Vol
188

LIFE AND EFFICIENCY OF ARC LIGHT CARBONS.

DISCUSSION OF LOUIS B. MARKS'S PAPER AT THE GENERAL MEETING, BOSTON, MASS., MAY 21, 1890.

(*See page* 175 *ante.*)

THE CHAIRMAN, PROF. ELIHU THOMSON:—I am sure we have all listened with great interest to the valuable paper of Mr. Marks and we hope that this subject, which is undoubtedly an important one, will elicit other opinions from the members. The paper is now open for discussion.

MR. G. W. BLODGETT:—I have been much interested in Mr. Marks's paper. But my experience with three or four isolated plants of the Brush system has been somewhat contrary to Mr. Marks's experience. He said, if I understood him rightly, that a very hard carbon is the best for a low tension system, and a very soft carbon for a high tension system. My experience with the Brush lamps has been just the reverse. I have got the best results with a very hard close grained carbon, plated with a thin plating of copper which seems to give better results than a bare carbon, or one heavily plated. He spoke of the difficulty of using the incandescent lamp in the photometer as a measure of the arc lamp. I presume those difficulties are quite as great, perhaps even greater, than he has said.

I had occasion recently to review some experiments which were made by Elston on a Siemens lamp in Berlin, lighting the Unter Der Linden. He states there that the difference in the color after a few hundred measurements, was of no consequence; that the photometer could be very exactly set using an incandescent lamp at one end and an arc lamp, or the reflection of it at the other end. He found that the lamps there, however, which were run at 2000 nominal candle power only gave from six to seven hundred. Mr. Marks also says that with low voltages a deep crater forms, while with high voltages no crater at all was observed. In a Brush lamp the craters which I have obtained were deepest when the machine seemed to have the highest voltage, although I got no accurate experiments.

He said also that with a high voltage and a small current there were mushrooms formed on the negative carbon, while with the large current they disappeared. With the old style of Weston lamp, which burns with a 20 ampere current and about 500 volts, these mushrooms were very much more troublesome, in my experience, than with a Brush lamp using about 10 amperes and a voltage of perhaps twice that amount. I would like to know whether any one has had a similar experience.

Prof. Thomson:—On my own account, having had considerable experience with the arc light system and its development, I might say that I think that Mr. Blodgett has not probably understood perfectly what was meant in the tests concerning the mushrooms. As I understand it, the voltage was to be kept constant notwithstanding the efforts of the lamp to regulate. Then a diminution of current will produce a concave crater, according to my experience, and the little point or mushroom extends into that crater. Suppose for example we have the ideal arc (Fig. 1) If now we diminish the current and maintain the voltage, the upper carbon will come down gradually and get nearer and nearer the other carbon; that is assuming that the regulation of the arc lamp is allowed to take care of the voltage or assuming that we take a measurement of voltage and also of current. As we reduce the current and keep the voltage the same, the result finally will be that we get something like Fig. 2 with a much smaller crater and a mushroom.

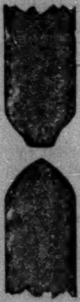
Fig.1

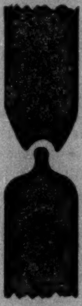
Fig.2

Mr. Blodgett:—That is exactly what I have observed.

Prof. Thomson: —That is, with a small current—reducing the current from 10 amperes to 5.

Mr. Blodgett:—I don't know about that. The lamp regulated itself.

Prof. Thomson:—Let us take the other case, not separating the carbons; we will find that the voltage then will drop and will finally build up a heavier mushroom and much widened crater. That is the condition spoken of, allowing the current to increase without the voltage being maintained constant. In fact, I have carried currents of such force through carbons that the crater was over the whole end and the mushrooms built up in the form shown in Fig. 3. so that we have nothing but a layer of vapor between. It must be said, however. that of course in this case we have a hissing arc. We have not the perfectly developed arc. The perfectly developed arc, in my judgment, implies about 40 to 50 volts and no hissing A remarkable fact, however, in that connection, is that with certain carbons it is possible to actually keep the current say at 10 amperes and bring the carbons almost into contact without a trace of a hiss. I have often noticed this which is, however, a peculiarity of what are called cored carbons. They are made with a soft graphitic core, (Fig. 4.) which apparently vaporizes with great ease and enables you to bring the carbon down with care so that no hissing is produced; but if you do it suddenly you may provoke hissing. I think one of the most interesting phenomena found in arc lamps is that of hissing. We have not yet found out what it is due to. But I think I can show an analogy which may point out what it is, or lead us to it. Hissing is most vigorous, so far as my experience goes, in carbons of coarse grain and it is more easily provoked in carbons of very coarse grain, especially when they are brought together. Now it is an old experiment in chemical operations to sublime sal-ammoniac in a dish. Sal-ammoniac gives off vapor when it is heated. If you do it vigorously and rapidly, you will hear the sal-ammoniac hiss and fry; but if the heating is applied moderately and slowly, there will be a gentle sublimation without noise. That leads me to think that the electrolytic vaporization, if we may call it that, that is the changing of the positive carbon into vapor, when this is too vigorous, or is so vigorous, as it were, that each little particle of carbon, when it gets into the crater, explodes, then you have a hiss; but if it actually vaporizes as water does when it is kept hot but not boiled, you have the ordinary quiet arc.

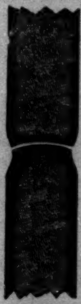

Fig.3

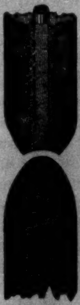

Fig.4

There is another point in regard to that matter. I say that sal-ammoniac illustrates the effect. Now we find with the cored carbon that the inner core is more volatile. It exposes more surface on account of the fine grain, and the hissing of very fine grained carbons, whenever they hiss, is not so harsh. With retort carbon, such as carbons were made of years ago, very dense in grain and very fine, the powdering was so done as to give an almost impalpable powder. The carbons generally formed a rather smaller crater than the modern carbons, and I have known them, when they were just on the point of hissing, to take up a very musical note—sometimes even whistle—and the whistling of a carbon of that kind is the same thing as hissing. It is so uniform in grain that the little explosions have a note.

In regard to the structure of carbon as brought out in the paper, I may say that I had occasion years ago to look into the carbon question, and we found, in the years 1881 and 1882, that it was absolutely impossible to get satisfactory carbons for high-potential systems. It was a matter of discussion whether we would not be forced to manufacture the carbons that we should use. I found that in looking over the carbons the best results were obtained with moulded carbons on high tension work, and that forced carbons or squirted carbons could not be made at that time to maintain a steady arc. Their efficiency was low. If they came anywhere near being right they were still liable to the moving about of the arc and flaming, far more than the moulded carbons. That led me to examine the structure of them somewhat and I found that on breaking the moulded carbons—simply making a fracture anywhere, and examining the moulded carbons as compared with the forced carbons there was an entire difference of appearance at the ends. The moulded carbons had a glistening fracture when looked at straight on and a dull fracture when looked at across; whereas, the forced carbons had a glistening fracture viewed from an angle and a dull fracture looked at on end, showing that the lay of the particles was entirely different in the two cases. The process of forcing the carbon seems to lay the particles in line so that they present their edges to you when you look straight on—consequently having a flaky nature. The fact is the carbon, being petroleum carbon, is formed in flakes in the die retort. The flakes when they are forced out by the press enter on edge and lie up sidewise and come forward that way, and that carbon has the peculiar grain mentioned; but in the moulded carbon, where the pressure is applied laterally, the particles can lie in any direction, and consequently some are presented to you flatwise, and when you look on the end of the carbon you see some facets; and I found by tests of hundreds of the very best carbons, that the one that was moulded and gave me the brightest, cleanest fracture on end and a simple dull fracture the other way gave the best arc. Then it would seem almost as though this good effect requires that evaporation should take place from the side of laminae of the carbon; that when the grain was sticking out as in the forced carbon you could not rely on the stability of the arc. It would leave one point of discharge and and take up others.

There is another fact in connection with arc work which probably accounts for the flaming to some extent. If we take a carbon and elongate the arc so that it tends to flame, we find that the arc plays between the ends and blunts the edges of the crater, as though there was no boundary line for the discharge. Consequently the heated air rushing up may carry the arc over the edge and make it overlap a little, because above there is carbon full of gases and the arc naturally takes the more volatile materials Why? Because there is with the more volatile portions perhaps less counter-electromotive force developed; less energy to be absorbed there in making vapor from it. Consequently the arc flames and runs up the side (Fig. 5.) pointing itself always on the negative.

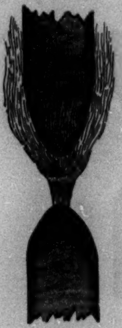

Fig.5

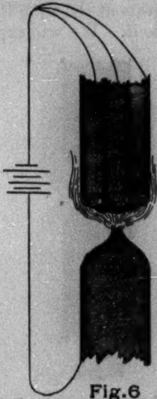

Fig.6

Another peculiar thing about the arc I noticed some time ago, and I find that Professor Fleming has recently investigated the same and other phenomena. You can readily have one negative in an arc and any number of positives, (Fig. 6.), but you cannot easily have one positive and any number of negatives form the same arc. You may bundle up sticks of carbon close together and leave them slightly separated and place a carbon opposite and you may have current running out of several of the positives to reach the negative, but you cannot have several negatives feeding a single positive, as it were, in multiple without special arrangements to secure the division of current at the negatives. In other words, the very fact that we have a crater means that we can have a great number of discharge points on the positive. The very fact that we do not have a crater or rather have a little point on the negative, indicates that we can only have one discharge point on the negative, or at least that one small space suffices for the current to pass. Otherwise the discharge would spread over and take up a larger area, at the same time.

Some of the most curious phenomena in relation to the effects of arcs burning are found in burning very large lights and I think that this is a subject which really requires some attention. I wish I had time to look into it. Take arcs burned with one hundred and fifty amperes or more and we find that the conditions for obtaining a quiet arc are much more difficult to preserve. The arc very easily gets into the unstable condition of hissing, and when it does it generally gives warning. I have seen it give warning about the time it was going to do that and sometimes fail to do it. We will suppose that a quiet arc is burning with a crater nine-sixteenths of an inch in diameter, and carrying a considerable current (Fig. 7.) The flame, of course, is considerable. There is a tendency to deposit carbon on the lower carbon. If the carbons are too near together the combustion is prevented and the carbon is deposited. But as I was saying the large arc will sometimes give warning of its tendency to hiss and generally begins at the negative carbon by the radiation of a series of striae of different color, and if they seem to reach near the positive, then you may be sure that the hissing has begun, because the fact is you will see the whole phenomena change, great masses will be cut out of the carbons and I have seen flames run off eight inches from the side of the carbon (Fig. 8.)—enormous roaring flames that could be heard all over the factory, and it is very difficult to quiet such an arc down again after it has once got started. Some of the arcs of large size now burned use cored carbon.

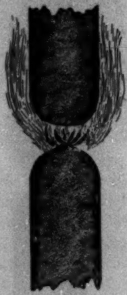

Fig.7

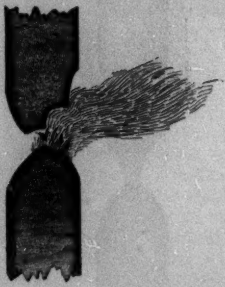

Fig.8

In fact that kind of carbon has done much to make it possible to run large arcs quietly.

Another style of carbon is one whose section is that of a fluted cylinder, so that we get the body of carbon and yet keep the arc on the center. (Figs. 9 and 10.) This I believe was due to Carre, the well known carbon maker. If that were also cored it would give excellent results. I must say that very many of the things brought out in the paper are confirmed by my experience and I am very glad to see them recorded. They are brought out in a scientific way, based on measurements, and that is the proper way to do it. In working along with arc lights we pick up a little here and there and finally accumulate a certain fund of information, but it needs to be classified and arranged, and I am glad to see that in this paper it has been done. I think attention of that kind should be given to this very subject.

In relation to a number of other matters it is not necessary to prolong the discussion. I should be very glad to hear from other members on the subject.

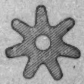

Fig.9

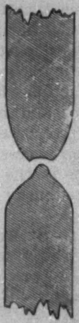

Fig.10

Mr. Marks: Mr. President, I would like to state in confirmation of what you said regarding the whistling of the arcs that I worked at this late at night when everything was absolutely quiet; that during the range of potential, starting a lamp from no voltage to a high voltage the sound varied in wave lengths it seemed to become higher and lower according as the voltage changed. The point in connection with the arrangement of the striae of the carbon in moulded and forced pencils are brought out I think clearly in Figures 9d and 12d in which you notice both forced pencils have parallel striations and also note that they lie in a longitudinal direction or in the same direction as the application of pressure used in the manufacture of carbons. The moulded carbons show the other instance.

Prof. Thomson has brought out the fact that quieting the arc is difficult to do with a large diameter of carbons. I would like to know if he has ever tried the means of doing this by the application of extraneous force; that is, having a number of lines of force circulating around the arc in such a direction as to keep the arc in the centre. I have tried that with considerable success.

Prof. Thomson:—I had that very arrangement one time, but it is a difficult matter to follow the arc and keep just the right position. It is making a certain magnetic whirl around the arc and feeding it along the arc. If by that means you can hold the arc in the centre, the tendency to flaming, as well as the tendency to hissing, is modified. I am glad to know it has been done successfully. I did not make any considerable experiments in that direction.

I would simply add that in regard to the life of carbons that my experience has confirmed perfectly what has been brought out in the paper that it is rarely that you get carbons, positive and negative, that burn in the ratio put down in the books—1 to 2. It generally departs from that relation considerably, and of course with low tension systems much more so, simply because of the plating action which saves the lower carbon. The carrying of carbon over and building up of the negative prevents the lower carbon from wasting by combustion when it is receiving constantly large accessions of new material. Consequently the positive carbon is the one that is consumed. It has to furnish the material to burn; while the negative is preserved by deposition.

Mr. Marks:—By having a suitable range between the plus and minus, it is very easy to obtain the plus and minus carbon that would burn away exactly at the same rate.

Prof. Thomson:—By using a very soft under carbon and hard upper carbon.

Mr. Marks:—Of the same diameter.

Prof. Thomson:—By focussing lamps geared at the same rate.

Mr. O. T. Crosby:—I should like, as a matter of information, as I am not very familiar with this branch of the work, to know whether it is perfectly safe to calculate the total life of the carbon by a rate determined from observation. In other words, is the rate of consumption uniform throughout its whole life? What you said concerning the building up of the lower carbon makes my doubt a little stronger; although I am not posted in the matter—because we appear to be building up a new pencil all the time, whose structure and consequently whose rate of consumption need not be the same during the different portions of its life as of any given portion.

Prof. Thomson:—As to this particular case of building up a new structure, by carriage and deposition of carbon on the negative, the way this added carbon is disposed of is not by combustion; the carbon pencil burns below the point of building and the piece above tumbles out. (See Fig. 12.) It is wasteful of carbon, because in this particular instance it simply protects the ends—until this dropping out action occurs—from being burned. This merely excludes the oxygen at the point and lessens the rate of burning. I think it would be possible with a perfectly formed arc, that is, with an arc burned at 45 volts, to calculate with most carbons the rate from one hour's burning. That is, the variation would not be very great. If the pressure in the moulding is uniform and in the forcing also, the structure may be considered fairly uniform. It would not be possible, however, to take the same make of carbons and several batches coming out at different times and calculate from the rate of one carbon taken out of one batch what would be the rate of all the batches, because they do vary and the carbon manufacturer cannot altogether help it.

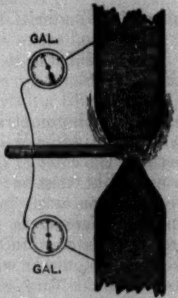

Fig.11

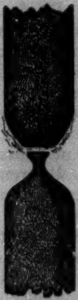

Fig.12

Note A with Fig. 11.

(Communicated by Prof. Thomson.)

This concerns electro-motive force differences between the arc flame and the respective carbons, positive and negative. This difference can be observed easily by inserting a small carbon rod into the arc with a voltmeter connected from the rod to the positive carbon for determining the difference of potential between the positive carbon and the flame, and also a voltmeter connection between the inserted rod and the negative carbon. Nearly the wholee lectromotive-force difference will be found to exist between the positive carbon and the inserted rod. This indicates that most of the work done in the arc is done in the positive electrode or where the current passes from the positive carbon into the gas or at the crater itself, which is the dividing line between them. It is natural, therefore, that the arc should spread itself out on the positive carbon and acquire a considerable area over which this work is done while at the negative carbon it should concentrate itself, as very little of the work is done there in the passage of the current from the gas stream to the negative carbon.

Mr. Marks:—I made a number of transverse tests of carbons from different batches and found that in one batch of carbons the ultimate strength was 41 3-10 pounds; while in another batch sent on some time later the ultimate strength was 48 pounds, showing that the carbons were not absolutely homogeneous.

Prof. W. A. Anthony:—The quality of the material, the temperature of baking, all those things, of course, make a difference in the carbon produced, and it is very difficult to control them all in such a way as to produce an absolutely uniform product.

I would like to say one word in regard to photometric tests. The remark was made here that it was found after working a number of hours on a photometric test that the color of the light made no difference, and while I have no doubt that in making photometric tests with arc lights by comparison with incandescent, one would become accustomed to the difference in color in such a way that while you get uniform results continuously, if you let some other man come and take the photometer with that conditions of things, I think the result would vary entirely. Probably the other man would go on and in the course of a few hours he would get so that he could get uniform results for himself. There would be a personal equation in there that would be a pretty serious matter.

Prof. Thomson:—I think that Prof. Anthony's remarks are very apt indeed. People undoubtedly have a different color scale, some people seeing far up in the violet and not so far down in the red. I have seen one case in which the color scale of the individual was simply yellow.

Mr. Franklin L. Pope:—I would like to ask Mr. Marks if he ascertained the character of the raw material that was put in the different makes of carbon with which he experimented; whether they were of the same or different sources such as pulverized carbon, or petroleum, or natural gas and the like?

Mr. Marks:—The manufacturers were very reticent in regard to that matter. I obtained information from two of the companies. I may state that the product of the second distillation of petroleum was used by one of them as the crude material, and a given amount was measured out and one-quarter of its weight of pitch was added. This formed the mass which was moulded into sticks. In another case I understood that one-third of the weight of pitch was added. This information was received from the factory. I cannot vouch for it. I have never worked in any of the carbon factories, and I would not like to commit myself.

Prof. Thomson:—I think it is safe to say that most carbon manufacturers to-day use petroleum carbon. Formerly some of them used the gas retort hard carbon, but it is so hard to grind and impure—iron and ash of coal naturally working into it—that it is only suitable in any case for use in low tension systems. Perhaps some of the forced low tension and very hard carbons are still produced from gas carbon, but we never found an instance in which such carbon was used successfully in high tension systems, on account of the volatile material—the ash—causing changes of color and causing the arc to "flame around," as we would call it.

Mr. Marks:—The statements was made a little while ago by one of the members that forced carbons are in some cases adaptable to high tension systems. I tried all the forced carbons that I could possibly find and I have not come across any that will give anything like as steady a light. There is the spluttering and hissing and flaming that Prof. Thomson alluded to, and besides this the light is apt to go out at times.

Prof. Thomson:—That accords perfectly with our experience. We have adopted moulded carbons for high tension work, and any one simply presenting us with a forced carbon and saying that it was for our work, would be told at once we did not wish to see it. We have been through that experience so often that there is no use in looking at it.

Mr. F. L. Pope:—I think it would be very desirable if some one could make a study of the battery carbon as Mr. Marks has the arc light carbon. I would like to make that suggestion, and if any one desires to follow it up I think the results would be of very great value.

Prof. Thomson:—That is an apt remark indeed. I am very much surprised that no one has done it in relation to battery carbons. The quality of battery carbons could undoubtedly be brought to a high plane by due attention to materials, making, etc.

Mr. F. L. Pope:—I would say in relation to that matter that I was asked to make a test of a battery carbon said to be made of sea weed carbonized. I obtained very good results from it indeed, perhaps better than with any other form of carbon that I could get hold of.

Prof. Thomson:—I can say in seconding that, that I was asked to make a test of arc light carbon made from sea weed carbon and I obtained very poor results from it. But I can readily see that the conditions were altogether different. The battery carbon requires to be porous to take up gas. I suppose it was an open circuit battery—sal-ammoniac—Leclanche?

M. F. L. Pope:—Yes.

Prof. Thomson:—And therefore required to absorb oxygen from the air, and the very absorptive power of the carbon was just the condemnation of it in relation to use in arc lights where you want the most thoroughly carbonized material you can get and as little absorbent as possible. If there is no further discussion of the paper just read we will take the next in order—a paper by Prof. Edward L. Nichols, of Cornell, entitled "Note on a New Photometer."

Read before the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.

NOTE ON A NEW PHOTOMETER.

BY DR. EDWARD L. NICHOLS.

Methods of photometry which take no cognizance of differences of quality are so ill adapted to the study of sources of light which differ from each other widely in temperature, that the introduction of some instrument by means of which both the character and the intensity of an illuminant can be readily determined, would be a desirable adjunct to the equipment of our photometer rooms.

The instrument which it is my purpose to describe has been designed to meet this need. Existing types of the spectro-photometer may be made to give good results, but they are expensive instruments and so difficult to use that it is only in the hands of observers of considerable experience that accuracy is assured.

The new apparatus, the "horizontal-slit" photometer, is in point of fact a spectro-photometer in which the polarizing device is entirely done away with. In it the extremely simple principle of the Bunsen photometer is applied successively to the various regions of the visible spectra of the source of light which are to be compared. A direct vision spectroscope of Browning's form is attached to the usual car of a Bunsen photometer, from which the disc and mirrors have been removed. The optical axis of the collimator is horizontal and at right angles to the photometer bar. The slit is horizontal and lies in a straight line, joining the sources of light, which are set up in the usual manner at the ends of the bar. The bar itself is preferably of considerable length (in the case of the one upon which the original instrument under consideration was mounted, it was 500 c. m. long) and should be divided into 1,000 equal parts.

In front of the spectroscope slit are placed two right angled prisms of the same size and made of the same glass (see Fig. 1.) Their vertical adjacent edges bisect the slit, and light traveling from either end of the photometer bar is totally reflected by them and enters the right or left hand end of the slit in a direction parallel to the optical axis of the collimator tube.

The two sets of rays thus gathered into the spectroscope from the lights at the end of the bar are vertically dispersed by the direct-vision prisms and appear in the field of view as two vertical spectra standing side by side. Equal wave lengths are in the same horizontal line and any desired region may be brought into the centre of the field by an angular movement of the ocular telescope. The telescope moves along the arc of a suitably divided semi circle, to which it may be clamped by means of a set-screw. Wave lengths corresponding to the various circle settings are determined once for all, by observation of the more prominent of the Fraunhofer lines.

When the instrument, thus mounted, is placed at the middle of the photometer bar, between lamps which are identical in intensity and quality, the two spectra are of equal brightness throughout, wave length for wave length, from red to violet. If the two lamps differ in intensity but not in quality, the two spectra will differ in brightness by the same amount from end to end, and a position may be found upon the bar for which they will be identical throughout.

Under these circumstances, which are the only ones in which the Bunsen method in photometry is strictly applicable, the instrument may be used as a simple photometer, the setting for any wave length whatever giving the candle-power. For this purpose alone, viz., for the comparison of lights of similar character, the instrument offers certain manifest advantages over the various forms of the Bunsen photometer. In the course of the present paper I shall present some definite data concerning the relative sensitiveness of the two instruments when used in this way.

When the lights to be compared differ both in intensity and quality, ordinary photometric indications possess no perfectly definite significance. In this, which is the more general case, the relative brightness of the spectra of the two sources varies with the wave length. For each region of the visible spectrum, however, a position upon the photometer bar can be found at which the brightness of the two spectra in that region will be equal, and the observations thus obtained, when extended over the entire spectrum, will afford data by means of which the differences in quality of the two sources of light may be definitely expressed.

In a recent paper read before the Institute,[1] I have shown that for a considerable range of temperature at least, the ratio between the intensities of a certain wave length of the spectrum of glowing carbon, is identical with the ratio of candle-powers as determined by the Bunsen photometer. The wave length in question, determined from the intensity of the spectrum of incandescent lamps at various candle-powers, I had found to be approximately $\lambda = 600$. M. A. Crova, in an important paper since presented at the late electrical congress at Paris[2] has pointed out the importance of this method of measuring the light from sources differing in temperature. The wave length which he has indicated for this purpose is $\lambda = 582$, which belongs to a region lying slightly further toward the green than the one which I had adopted.

When the wave length of this region has been established beyond question, the photometry of lights which vary in color, will have been reduced to a definite scientific basis. Instead of attempting to use the Bunsen photometer in measurements to which it is not adapted, we shall be able to deduce the relative candle power of two sources of light from the comparison of a single wave length, and we shall be freed from the uncertainty arising from differences of colors and from the personal errors due to the independent use of the two eyes in observation. The determination of candle-power will then be an operation of precision, even when the sources of light to be compared vary widely in temperature. It is in the opportunity of performing such observations upon the photometer bar itself, under conditions which do away with many of the sources of error inherent in the usual methods of spectro-photometry, that the chief advantages of the new photometer will be found to lie.

The following set of observations, taken with the new instrument, may serve to indicate one of the uses to which it may be put. The data are taken from an investigation now in progress in the Physical Laboratory of Cornell University. The object in view was to compare the spectrum of a novel type of gas burner with that of an ordinary argand burner. The two lamps were set up at the ends of a photometer bar five meters long, the bar, as already stated being divided into 1,000 equal parts. Readings were taken at six points in the spectrum. The purpose being to express the relative brightness of the two spectra, wave length for wave length, the intensity of that due to the argand burner was taken as unity throughout, and the brightness of each region of the spectrum of the flame under investigation was obtained in terms of that of the corresponding region of the spectrum of the argand. The results are given in Table 1:

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[1] TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, vol. 6, p. 183.

[2] M. A. Crova, *La Lumiere Electrique*, vol. 33, p 478.

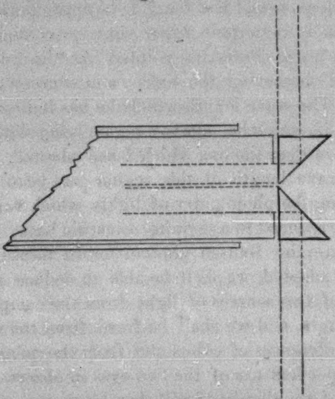

Fig. 1.—A New Photometer.

Table 1.

Comparison of the spectrum of a Welsbach burner with that of an ordinary argand burner, by means of the "horizontal-slit" photometer.[3]

Color.	Wave length	Light-ratio $\frac{\text{Welsbach}}{\text{Argand}}$	Probable error of a single observation.
Red	702	0.709 ± .017	2.45%
Yellow	589	1.476 ± .017	1.14%
Green	558	1.760 ± .023	1.34%
	500	2.395 ± .047	1.99%
Blue	466	2.738 ± .036	1.30%
Violet	439	3.090 ± .073	2.35%
			1.76% (average)

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3. From observations by Miss Ida M. Hill.

Ten observations were made in each region.

I introduce these measurements here simply as an illustration of one line of work to which the instrument under consideration is adapted. A full description of the research of which they form a part, and which covers many other questions pertaining to the very interesting class of lamps with which it deals, will doubtless be published in due time.

As will be seen from the column of probable errors, the sensitiveness of the instrument is greatest in the region of the D line ($\lambda = 589$) and least in the extreme red and violet, where the light intensities are small.

A set of ten determinations made by the same observer with the Bunsen photometer, gave for the total light-ratio of the two lamps:

$$\frac{\text{Welsbach}}{\text{Argand}} = 1.701 \pm .015$$

The probable error of a single observation in this series amounted to 0.89%, a value somewhat smaller than that obtained with the new photometer in the yellow of the spectrum.

The number of observations is too small to afford a close estimate of the relative sensitiveness of the two instruments, but the results suffice to show that the "horizontal-slit" photometer does not differ appreciably in accuracy from the Bunsen photometer when the latter is used in the comparison of flames of the same color.

When it comes to the measurement of sources of light that differ widely in temperature, the comparison is decidedly in favor of the "horizontal-slit" photometer, the sensitiveness of which is not affected by differences of color. The error of the Bunsen photometer in candle-power measurement of the arc light, for instance, calculated from ten observations recently made upon the same photometer bar, the reference standard being an argand gas burner, was 2.65% (probable error of a single observation), a value more than twice as large as that of the "horizontal-slit" photometer.

A comparison of the performance of the new photometer with that of a polarizing spectro-photometer of the type which is commonly recognized as affording the highest degree of accuracy, is likewise decidedly in favor of the former. Taking as a basis eight observations made by Mr. Franklin and myself in the study of a bat's wing gas burner,[4] the observations covering eight regions of the spectrum, I find the error of a single observation, in the various regions to have been as follows:

TABLE 2.

Probable errors of a single observation with a polarizing spectro-photometer, calculated from sets of ten observations upon various portions of the spectrum of a gas flame.

Wave lengths.	Probable error of a single observation.
753	7.9%
668	4.9%
608	4.5%
557	5.4%
518	6.4%
492	7.0%
468	3.0%
450	2.4%
	5.2% (average)

The measurement of a fluctuating illuminant, such as the gas-flame, is a line of investigation by no means adapted to exhibit any photometric instrument at its best; but as the errors of the horizontal-slit photometer, already given, were calculated from sets of ten observations upon such flames, I have selected for comparison similar sets of ten upon sources of the same character.

The averages, viz.:

Error of horizontal-slit photometer, 1.76% (average for spectrum),

Error of polarizing spectro-photometer 5.20% (average for spectrum),

doubtless afford a fair indication of the relative performance of the two instruments in this peculiarly trying line of work.

At the last annual meeting of the Institute I had the privilege of presenting a brief study of certain personal errors pertaining to the use of the Bunsen photometer. The particular class of errors to which attention was called in that paper[5] are undoubtedly obviated by the use of the horizontal-slit-photometer; what new ones the latter instrument may introduce remains to be determined.

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[4] *American Journal of Science*, vol. 38, p. 100. See also TRANSACTIONS OF AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, vol. 6, p. 177.

[5] TRANSACTIONS OF THE AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, vol. 6, p. 335.

DISCUSSION.

MR. F. A. C. PERRINE:—I beg to ask Doctor Nichols how he calculates the light from the illumination given in different parts of the spectra? Do you compare it with the yellow light?

DR. NICHOLS:—I do not know whether I fully understand the gentleman's question. The point is this—that if you take an arc light the intensity of which the Bunsen photometer shows is ten times greater than the incandescent lamp; and then take the spectrum of the arc light and the spectrum of this incandescent lamp and place them side by side, it will be found that in the region of yellow these spectra are as ten to one, and having once set up a standard of that kind you can test relative candle powers by comparing this portion of the spectrum only. I do not think this standard wave length has yet been determined with sufficient care. In a paper which I read before the Institute somewhat more than a year ago[1] I explained this matter more fully. I do not know what this particular wave length depends on, but it is possible to find it, and having found it the setting of the photometer for different qualities of light becomes as simple as the setting of a Bunsen photometer for lights that are just the same.

PROF. THOMSON:—As I understand it, if we simply have blue or green light to deal with, of course that is ruled out of the question. We cannot give them value in terms of the yellow.

DR. NICHOLS:—I think it is probably true only of the spectrum of incandescent carbon. I am quite sure that this standard wave length is different for lights of different sources.

THE CHAIRMAN:—If there is nothing further we will close the discussion and the Secretary has some announcements to make.

The Secretary read invitations from the Boston Society of Civil Engineers, and from the Union Electric Car Company, extending their courtesies to the members of the Institute.

MR. CROSBY:—Mr. President, I think some formal action had best be taken to recognize the kindness of the civil engineers in extending the invitation, although I do not see how it would be possible to accept it for any trip to-morrow, as the West End trip and the visit to Lynn will occupy the day. I move a vote of thanks, while we cannot, on account of pressure of time, accept any definite hospitality.

The motion was carried.

A recess was taken until 2.30 P. M.

AFTERNOON SESSION.

THE CHAIRMAN (Prof. Elihu Thomson):—I have the pleasure of informing the Institute that our newly elected President, Professor Anthony, will now take the chair. I have succeeded in prevailing on him to preside for the rest of the meeting. I know of no one more worthy or more able to conduct the proceedings of the Institute than Prof. Anthony, and I will say in stepping down from the chair that I feel that I have not been able to do quite what I should have liked during the past year. I have presided at very few meetings, and it has been because I was busy and because I was not on the scene, and because it happened that when I was in New York the meetings would occur about two or three days afterwards. So without further excusing myself I will give the chair to Prof. Anthony.

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[1] See TRANSACTIONS. Vol. vi., p. 158.

PROF ANTHONY :—Gentlemen of the Institute, I must say the announcement to me this morning just at the moment the meeting was called to order that I had been elected President of the Institute, took me entirely by surprise. I had come here with the idea that Prof. Thomson was to preside at this meeting in Boston, and it seemed to me that he was the proper man to take charge of it. I certainly did not feel as though I had any claims whatever upon the Institute. I may say that I have been thoroughly interested in the work of the Institute. I have been interested in electric work for a great many years, and have been a member of the Institute for some time, and have been present at its meetings whenever it was possible for me to be. I have always kept watch of whatever was going on in the Institute, and have felt that a great deal of good was coming continually from these meetings. I thank you most heartily for the confidence that you have placed in me in electing me to this position. As I said before, I do not feel that there is any special reason why I should have been called to this place, and certainly you might have found some one else who could always be present at the meetings, or who had at least done more to deserve the honor that you have conferred. I certainly feel that it is a great honor to have been chosen by such a body as this to represent it.

We will now proceed to business. The first paper of the afternoon is " On the Limitations of Steam and Electrical Transportation," by Oscar T. Crosby, of New York City.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21, 1890.

THE LIMITATIONS OF STEAM AND ELECTRICITY IN TRANSPORTATION.

BY O. T. CROSBY.

"Do you expect electrical engines entirely to displace steam locomotives on all railroads?" That is a question which has doubtless been propounded to many electrical engineers. Its answer has doubtless been made, in general, by wise reference to the boundless possibilities of direct production of electrical energy from heat, and to Bellamy's "Looking Backward" storage batteries.

To make some study of the boundary line dividing the province of steam locomotion from that of electric locomotion—under existing conditions of producing electric energy—is the the object of this paper.

In the light of present achievements I may state, without argument, the following propositions:

First—It is possible to construct motors capable of doing the maximum work required to-day in transportation.

Second—It is possible continuously to generate electric energy equal to the capacity of any number of such motors.

Third—At any desired loss and over any desired distance it is possible to supply by the running contact method, the necessary current, at considerable pressure, for the working of such motors.

Should there still be question in the minds of any, as to the value of the running contact method at speeds much higher than those commonly used, I may state that I have seen 75 amperes at 500 volts thus continuously supplied to a car moving at more than 110 miles an hour.

These premises being established, further discussion divides itself into three parts.

First, as to the mere possibility, without reference to the economy, of steam and electric propulsion under given conditions.

Second, as to the relative cost of exerting, in a locomotive, any unit of power by electric, as compared with direct steam motors.

Third, as to the relative amount of power required by the two agents to transport a given paying load under given conditions.

In using the word steam, as above, I have in mind only the direct application of steam power on the tracks. The case of cable propulsion is not here compared, as that has, within its restricted field of application, already been compared with horse, steam, and electric power.

The limiting possibilities of locomotion may be understood by considering a prolongation of the lines of present practice in the direction, first, of loads handled; second, grades climbed; third, speeds attained; fourth, length of continuous runs.

Since the effect of grade, as compared with load, is simply to increase the tractive effort required for a given load and speed, it need not be separately treated, except that there has been some question of increase of adhesion, in the ground return method, which in extreme cases might appear as an advantage for electric propulsion. The matter is not of great importance, and I will refer to it only so far as to say that interpreting my own general experience and some special tests, the adhesion coefficient seems not increased in any practical degree by the mere passage of the current from wheel to rail.

The capacity of an electric engine, like that of a steam engine, to haul any given load, will be measured by the tractive effort possible to be produced and the relation between weight and adhesion for given track conditions. The ready multiplication of cylinders in the one case and armatures in the other, while maintaining mechanical unity as to drawbar division, and the ready coupling of distinct locomotive units renders the whole question of capacity to exert a given horizontal effort, without regard to the time element, unimportant and indefinite.[1] It

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[1] As an interesting example of an unusual load in steam service, I may refer to one consisting of 156 loaded cars and two cabooses, hauled over the Mississippi Valley Railway, December, 1885. The load consisted of—

	Pounds.
Cotton weighing	3,226,000
Cars weighing	3,239,000
Engine and tender weighing	147,000
	6,612,000

Speed was about 10 miles per hour.

goes without saying that, if desired, a single armature may be constructed capable of exerting as great a drawbar strain as any locomotive now in use.

As to limiting speeds, it is not easy to-day to make "an educated guess" either for steam or electric propulsion. The high figures for steam that have been recently presented, both from England and America, are higher than the limiting figures as they would have been given by many competent authorities only a few years ago. Eighty-six miles per hour in England, on the Northeastern Railway, eighty-seven miles per hour in this country on the Reading Railway, have both been reported since January 1, 1890. These runs are noteworthy, not only for the fact of unusual speed, but because, as shown by indicator cards in the English case, and as may be deduced from the consideration of the maximum cylinder power in the American case, the train resistances are far below the values that would have been predicted by even the most liberal of the received formulæ on the subject. The total resistance per ton, as per indicator card in the 86-mile run, was only 13.4 pounds. According to Searles's formula, adopted by Wellington, it should be 69 pounds, engine and tender being taken at 50 tons. The load of 347 tons was carried at 86 miles per hour by an expenditure of 1,068 h. p.—this on a level. The engine was compound.

Would it be possible to attain a speed twice as great, or say 150 miles per hour?

A driver 24 feet in circumference would require to revolve 550 times per minute in order to travel 13,200 feet per minute, or 150 miles per hour—this without slip. Since in the case considered the revolutions per minute reached 309, and since in the Reading case a much higher rate must have been reached, the drivers being smaller, and since on stationary engines a speed much above 550 revolutions per minute has been attained, it seems beyond question that from this point of view the supposed case is quite possible.

Considering the matter of steam supply, we are again brought to consider the whole matter of train resistances at all speeds.

Total resistance to motion should be sharply divided into two classes: the resistance due to motion through air, and that due to friction and blows between vehicle and track, and to friction and blows between parts of the vehicle.

For the most part those who constructed the formulæ now found in the text-books, worked on roadbeds far inferior to the best work of to-day, at speeds much less than those now attained and with wrong values for at least one of the species of resistance, the atmospheric. On this point I have recently been able to present as the result of experiments at high velocities, made by Mr. Benj. J. Dashiell, Jr., and myself, a formula showing the pressure to be a function of the first, instead of the second, power of the velocity, as ordinarily assumed. A convenient datum point may be given stating that at 100 miles per hour the pressure on one square foot, normal to the direction of motion, is 13 pounds, while proper shaping of the front may reduce this 6.5 pounds.

The absolute values given, while corresponding quite closely with those of received formulæ in the neighborhood of the velocities heretofore experimentally attained, depart widely from those assumed for velocities higher than 30 miles per hour, and calculated by the quadratic relation between velocity and pressure. Using the more trustworthy values, I have been able to separate more nearly than has heretofore been possible the atmospheric from all other resistances met at high velocities. Some inaccuracy still remains, by reason of the difficulty of obtaining exact measure of the resisting areas in a train, but I have been able by study of careful tests made by others on the New York Central and on English roads, to find that over the range from about 40 up to 80 miles per hour the tonnage co-efficient seems practically constant at 8 pounds. This, of course, applies only to first-class roadbed and rolling-stock. Whether this co-efficient remains constant at higher speeds we do not know. There is no reason to assume, as has often been done, that it increases with the square of the velocity, and on the other hand it will not be safe to assume constancy. From experiments made with a single 2.5 tons car at about 100 miles per hour, the tonnage resistance at that speed seems to be about 20 pounds per ton. Though this value seems quite high as compared with the eight pounds at 85 miles per hour, the difference is in large part to be explained by the poor condition of the track used for the experiment and a constant curvature which would call for about four pounds per ton. Until better evidence can be had it will be safe, at least, to assume a value of 20 pounds per ton, on a first-class track, with good rolling-stock, at 125–150 miles per hour.

Having made this necessary digression, we may return to the matter of steam supply, and state that by reducing weight and area, both to something less than one-half the original values in the 86 mile run, the same effort would produce the speed 150, instead of 86. The area cannot be thus reduced, but by assuming a greater reduction in weight—say to 100 tons, or to little more than engine and tender—maintenance of the higher speed becomes possible, with nearly the same steam expenditure as in the recorded case.

To attain that speed, from rest, might require such original weight of fuel and such length of favorable track as to make the feat practically impossible with steam. This leads us to inquire into the dead weight necessary for hauling, say one ton at different speeds.

Table I. gives the horse-power required for exerting the tractive effort for one ton at various speeds. at various efficiencies, with various values of cross-section per ton, and with the two agents—steam and electricity:

Column 1 shows speed in miles per hour from 20 to 140; column 2, corresponding tonnage co-efficient, or resistance, in pounds per ton, exclusive of atmospheric resistance. Columns 3 to 8 inclusive, show horizontal effort needed for overcoming atmospheric resistance under various assumptions as to area exposed per ton, from 1 square foot to 0.1 square foot per ton. The former figure corresponds nearly to the case of a heavy locomotive propelling itself alone. As load is put on behind it, other ratios are formed. Oblique surfaces are supposed to be reduced to equivalent normal surfaces. Columes 9 to 14 inclusive, show rate of work in horse-power per ton, for the various cases of area exposed to atmospheric resistance, efficiency of locomotive being taken at 90 per cent. Columns 15 to 17 inclusive, show horse-power per ton for the extreme and middle cases of exposed area, and for locomotive efficiency of 80 per cent. Columns 18 to 20 inclusive, show same for efficiency of 60 per cent. Columns 21 to 26 inclusive, show weight of coal and water per ton carried for one hour, assuming 5 lbs. of coal and 15 lbs. water per horse-power hour on a steam locomotive. The coal figure is very close to actual practice. The water figure is less, but makes allowance for scooping water at convenient intervals. Continuous scooping is not considered practical or economical. Columns 27 to 29 inclusive, show weight of steam locomotive and tender required to generate the required horse-power per ton, under the assumption of 100 pounds per horse-power and 90 per cent. efficiency. Only three cases of exposed area are taken; that is, one foot, one-half a foot, and one-tenth of a foot per ton. The weight of steam locomotives is not calculated for any other efficiency figure than 90 per cent., as this seems to be quite constantly attained or surpassed. The assumption of 100 pounds per horse-power is closely true for many good types of locomotive when working at speeds from 60 to 80 miles. At lower speeds this figure is too low, but it is assumed that for any ruling speed engines may be built of minimum weight for that speed. In passing through lower than ruling speeds, both electric and steam motors work at low output per pound of weight, hence the assumption of constant weight per horse-power will not introduce error materially affecting comparative results. At higher speeds than 80 miles existing engines would show less than 100 pounds per horse-power; but as their boiler capacity is reached at that speed, the necessary increase for any regular work would carry the weight figure to very nearly the figure given for the 60 to 80 mile running. Columns 30 to 32 show weight of steam locomotive and tender, plus weight of fuel and water, per ton hauled; also weight of load—freight and freight car—that may be hauled by such weight of motive power; the load figures being obtained by subtracting the motive power weights from 2,000 pounds. Columns 33 to 41 show corresponding figures for electric locomotives under the assumption of 60 pounds per horse-power, and at the three efficiencies; 90, 80 and 60 per cent. In 30 to 41 inclusive, weight of load is written first, weight of locomotive (plus tender, fuel and water for steam) being written below.

The 60 pounds per horse-power covers weight of containing car for motors. I cannot here go into detailed figures on this point, but believe that any investigation will find the figure safe, supposing always that the unit be, say 25 horse-power or more. I also know of experimental work now progressing under most competent direction, which gives fair promise of leaving this figure much too high. Columns 42 to 53 inclusive, show the *horse-power required to be exerted for hauling one ton of load, i. e.*, freight and freight car, the relation between these two being taken as the same for either steam or electric propulsion; hence not necessary to enter here. These columns apply to steam at 90 per cent., and to electricity at 90, 80 and 60 per cent., and for the three cases of exposed area. They are readily obtained from the previous columns by making allowance for the horse-power necessary to haul that part of every ton, total weight, which must go into motive power, machinery and fuel. Columns 54 to 62 inclusive, *show the ratios between horse-power required by the two agents for hauling a ton of load (freight and freight car) at the different speeds, efficiencies and area relations.*

It is plain that if we can now obtain the ratio of cost per horse-power, as given by the two agents, in the corresponding cases, we can easily determine the speeds at which the one or the other agent becomes the most economical.

Let us first obtain the cost in electric propulsion.

For this, form table II., showing the elements in the *cost* of one horse-power in stations of various capacity—from 100 to 3,000 horse-power. Engineers and dynamo-men are assumed to receive 40 cents per hour, and to superintend a maximum of 1,000 horse-power. This would produce, in some cases, fractional engineers, as for a 1,500 horse-power plant, but such complication has been avoided by assuming a constant value per unit of power, in the pay-roll element in plants exceeding 1,000 horse-power. Firemen and helpers are taken at 30 and 25 cents per hour, respectively. Superintendence, at 30 cents per hour, is apparently low, but is equivalent to 60 cents for daylight hours, since the plant is able to run 24 hours with the same general superintendence as for 12 hours. It is further supposed that the total of this item will not require increase until the capacity reaches 3,000 horse-power, beyond which it remains constant per unit of power. As no other element of cost is supposed to vary be-

TABLE II.

ELEMENTS OF THE COST OF ONE H. P. HOUR, ELECTRIC, IN CENTS.

Capacity	100	300	500	800	1,000	1,500	2,000	3,000	4,000	5,000	6,000
Engineer	0.4	0.13	0.08	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Fireman	0.3	0.10	0.06	0.037	0.03	0.03	0.03	0.03	0.03	0.03	0.03
Dynamo man	0.4	0.13	0.08	0.05	0.04	0.04	0.04	0.04	0.04	0.04	0.04
Helper	0.25	0.08	0.05	0.031	0.025	0.025	0.025	0.025	0.025	0.025	0.025
Superintendence	0.30	0.10	0.06	0.037	0.03	0.02	0.015	0.001	0.001	0.001	0.001
Coal	0.475	0.475	0.475	0.475	0.475	0.475	0.475	0.475	0.475	0.475	0.475
Oil, waste and water	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15	0.15
Interest and depreciation steam plant	0.057	0.051	0.044	0.033	0.028	0.022	0.022	0.022	0.022	0.022	0.022
Ditto electric plant	0.057	0.051	0.044	0.033	0.028	0.022	0.022	0.022	0.022	0.022	0.022
Ditto building	0.028	0.026	0.022	0.168	0.014	0.011	0.011	0.011	0.011	0.011	0.011

Speed.	Tonnage.	Areas exposed per ton in sq. ft.						
		1.0	0.75	0.5	0.25	0.2	0.1	
		Horizontal effort.						2 and 3
20	8	2.6	1.95	1.3	0.65	0.52	0.26	0.61
40	8	5.2	3.90	2.6	1.3	1.04	0.52	1.56
60	8	7.8	5.85	3.9	1.95	1.56	0.78	2.77
80	8	10.4	7.80	5 2	2.6	2.8	1.04	4.32
100	12	13.0	9.75	6.5	3.25	2.6	1.3	7.32
120	15	15.6	11.70	7.8	3.9	3.12	1.56	10.79
140	20	18.2	13.65	9.1	4.55	3.64	1.82	15.67
1	2	3	4	5	6	7	8	9

Speed.	Tonnage.	Coal and water for one hour. 5 lbs. coal. 15 " water.						Locomotive and tender at 100 lbs. per H. P.		
		2 & 3	2 and 4	2 and 5	2 and 6	2 & 7	2 & 8	2 and 3	2 and 5	2 and 8
20	8	12.3	11.66	10.65	10.12	9.9	9.6	61.6	58.3	48.4
40	8	30.8	27.9	24.6	21.30	21.07	19.8	154	139.7	99.0
60	8	55.4	48.6	41.8	35.0	33.4	30.8	277	243	154
80	8	86.2	73.9	61.8	49.3	47.1	42.1	431	370	210
100	12	146.5	131.2	108.2	89.0	84.3	77.8	732	636	389
120	15	215.4	187.88	160.	133.0	127.4	116.8	1078	939	584
140	20	313.5	276.0	237.	201.0	195.1	179.1	1567	1380	895
		21	22	23	24	25	26	27	28	29

Speed.	Tonnage.	Power for one ton freight and car, steam. 10 per cent.			Power for one ton freight and car, electric. 10 per cent.			Power for one ton electric at 20 per cent.		
		2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8
20	8	0.633	0.55	0.49	0.62	0.54	0.48	0.715	0.68	0.56
40	8	1.72	1.34	1.05	1.63	1.07	1.02	1.88	1.46	1.15
60	8	3.32	2.44	1.70	3.02	2.23	1.61	3.48	2.55	1.87
80	8	5.83	3.82	2.28	4.96	3.3	2.13	5.74	3.91	2.55
100	12	13.05	8.60	5.12	9.38	6.44	4.42	11.08	7.54	5.09
120	15	30.4	17.8	9.0	15.9	10.5	7.08	19.25	12.5	8.35
140	20	260.8	62.0	19.3	295.6	18.46	11.8	38.2	22.7	14.63
		42	43	44	45	46	47	48	49	50

The figures "2 and 3," "2 and 5," etc., indicate combination of the tonnage co-efficients in Col.

TABLE I

in H. P., 10 per cent. loss.				H. P. at 20 per cent. loss.			H. P. at 40 per cent. loss.		
and 5	and 6	2 and 7	2 and 8	2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8
[illegible]	0.501	0.49	0.48	0.70	0.07	0.55	0.93	0.8	0.73
[illegible]	[illegible]	1.05	0.99	1.77	1.40	1.12	2.37	1.86	1.5
[illegible]	1.75	1.67	1.54	3.15	2.37	1.77	4.20	3.2	2 37
[illegible]	2.46	2.35	2.00	4.90	3.50	2.37	6.53	4.6	3.2
[illegible]	4.45	4.27	3.90	8.32	6.15	4.42	11.1	8.16	5.9
[illegible]	6.65	6.37	5.84	12.21	9.12	6.66	16.3	12.2	8.85
[illegible]	[illegible]	9.75	8.95	17.80	13.5	10.17	23.0	18.0	13.5
11	12	13	14	15	16	17	18	19	20

Machinery and Fuel; load. Steam. 10 per cent.		Weight: Load; and weight of Machinery. Electric. 10 per cent.			Weight: Load; and weight of Machinery. Electric. 20 per cent.			Weight: Load; and weight of Machinery. Electric. 40 per cent.		
2 and 5	2 and 8	2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8
1931	1943	1964	1968	1971	1958	1964	1967	1944	1952	1956
69	57	36.6	32.	28.8	42.	36.	33.	55.8	48	438
[illegible]	1881	1906	1926	1941	1894	1916	1933	1858	1888	1910
[illegible]	119	93.6	73.8	59.4	106.2	84.	67.2	142.2	111.6	90
[illegible]	1815	1834	1875	1908	1811	1858	1892	1738	1808	1858
[illegible]	185	166.2	125.4	92.4	189.0	142.2	106.2	262	192.	142.2
[illegible]	1748	1741	1820	1880	1706	1790	1858	1608	1724	1808
[illegible]	252	259.2	180	120.	294	210.0	142.2	391.8	276	192
[illegible]	1523	1561	1676	1766	1500	1631	1735	1334	1510	1646
[illegible]	477	439.2	324	234	499.2	369	265.2	666	489.6	354
[illegible]	1299	1354	1518	1650	1268	1453	1600	1022	1268	1469
[illegible]	701	646.2	481.8	350.4	132.6	547.2	399.6	978	732	531
[illegible]	926	1060	1287	1517	932	1190	390	584	920	1190
[illegible]	1074	940.2	712.8	483.	1068	810	610.2	1416	1080	810
[illegible]	32	33	34	35	36	37	38	39	40	41

electric. 40		H. P. Steam. H. P. Elec. Loss on both. 10 per cent.			Ditto. Loss Steam 10 per cent. " Elec. 20 per cent.			Ditto. Loss Steam 10 per cent. " Elec. 40 per cent.		
[illegible]	2 and 8	2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8	2 and 3	2 and 5	2 and 8
[illegible]	0.75	1.01	1.08	1.02	0.88	0.81	0.87	0.66	0.67	0.65
[illegible]	1.57	1.05	1.05	1.03	0.91	0.92	0.91	0.67	0.67	0.66
[illegible]	2.55	1.1	1.09	1.05	0.95	0.95	0.91	0.69	0.68	0.66
[illegible]	3.54	1.17	1.16	1.07	1.02	0.98	0.90	0.71	0.71	0.65
[illegible]	7.17	1.39	1.33	1.16	1.17	1.14	1.00	0.78	0.8	0.71
[illegible]	12.0	1.01	1.7	1.27	1.58	1.42	1.08	0.95	0.92	0.75
[illegible]	[illegible]	8.8	3.35	1.64	7.00	2.7	1.39	3.2	1.6	0.85
[illegible]	53	54	55	56	57	58	59	60	61	62

pheric resistance shown in Col. 3 or Col. 5, etc , as the case may be. Similar reference is made in Table V.

yond this point, the table shows here a minimum total cost per unit, and a constant cost beyond it.

Coal is assumed to cost $3.00 per ton, and to be consumed at the rate of 3.2 pounds per electric horse-power hour in the dynamo. A very slight error is made in taking the rate of consumption as constant while changing the capacity of the engines.

Cost of steam plant is taken to vary from $50 per horse-power in a small plant to $20 in a plant of 1,500 horse-power. This latter figure may seem too low to some, but I have recently seen the figures for an 800 horse-power plant, in a neighboring Massachusetts city, which cost, in place, at the rate of $22 per horse-power.

Dynamo plant is taken to vary from $50 to $20 per horse-power in going from 100 to 1,500 horse-power. I know that machinery of good design can be manufactured for these prices.

The cost of buildings is taken to vary from $25 to $10 per horse-power. This is the most indefinite item. Interest, maintenance and taxes are roundly assumed at 10 per cent. per annum on the whole plant.

With Table II. as a basis, Table III. has been calculated, giv-

TABLE III.

TOTAL COST OF ONE H. P. HOUR.

Output in per cent. of capacity while working.	Hours of work per day.	Capacity of Station.							
		100	300	500	800	1000	1500	2000	3000
100	24	2.42	1.29	1.06	0.9148	0.860	0.835	0.825	0.816
"	18	2.52	1.30	1.115	0.938	0.883	0.855	0.849	0.829
"	12	2.85	1.52	1.228	1.028	0.955	0.95	0.895	0.867
90	24	2.62	1.36	1.12	0.947	0.88	0.86	0.85	0.83
"	18	2.77	1.45	1.17	0.98	0.91	0.88	0.87	0.853
"	12	3.10	1.61	1.29	1.06	0.99	0.94	0.925	0.89
80	24	2.87	1.45	1.18	0.987	0.92	0.91	0.88	0.86
"	18	3.06	1.55	1.23	1.03	0.98	0.936	0.926	0.90
"	12	3.42	1.73	1.37	1.13	1.06	1.000	0.98	0.95
70	24	3.19	1.57	1.26	1.04	0.96	0.925	0.91	0.89
"	18	3.42	1.68	1.32	1.09	1.01	0.952	0.94	0.91
"	12	3.82	1.90	1.48	1.19	1.09	1.02	1.01	0.97
60	24	3.62	1.73	1.36	1.11	1.01	0.975	0.96	0.94
"	18	3.83	1.85	1.44	1.16	1.06	1.015	1.00	0.965
"	12	4.31	2.11	1.63	1.30	1.17	1.085	1.07	1.015
50	24	4.22	1.95	1.52	1.20	1.10	1.045	1.03	1.00
"	18	4.50	2.10	1.61	1.27	1.15	1.09	1.076	1.039
"	12	5.09	2.40	1.83	1.43	1.28	1.19	1.17	1.114
40	24	5.11	2.28	1.73	1.35	1.21	1.15	1.13	1.10
"	18	5.47	2.48	1.88	1.44	1.33	1.25	1.23	1.17
"	12	5.2[illegible]	2.82	2.17	1.64	1.50	1.38	1.35	1.28
30	24	6.63	2.84	2.10	1.59	1.40	1.325	1.30	1.26
"	18	7.28	3.02	2.27	1.71	1.51	1.40	1.38	1.32
"	12	8.06	3.52	2.65	1.98	1.73	1.57	1.54	1.44

ing total cost per horse-power hour in stations of various capacities, working at various percentages of full capacity and for 24, 18 and 12 hours per day, respectively.

A glance at the table shows that in a 100 horse-power plant the cost varies from 2.42 cents for a 24 hour run at full capacity, to 8.06 cents for a 30 per cent. output continued only 12 hours per day.

This extreme case would doubtless be ameliorated by dropping the superintendence and combining engineer and fireman—though to this the unions might object. This capacity is smaller than need be considered for any steam-line service.

The minimum cost given by the table is 0.816 cent; this for a 3,000 horse-power plant, working full capacity 24 hours per day.

The next element of cost—that of the conductors for the current—is obtained from Table IV. showing investment in dollars for the copper required to transmit one horse-power a distance of one mile, at varying initial and final pressures. The constants for this table were thus obtained: Taking a well-known line wire, I find that from No. 4 to No. 000 B. W. G., the average weight ratio of insulated to bare wire, per unit of length, equals 0.844. When bare copper sells at 15 cents, this insulated wire sells at 20 cents = 22.5 cents on the copper alone, when insulated. If, therefore, we take copper at 25 cents per pound we provide for a very good insulation. The cost of one mil-mile is thus found to be $0.004. Combining this with the familiar formula.

$$C\ M = \frac{16{,}600 \times \text{h. p. transmitted} \times \text{distance in feet.}}{\text{E. M. F. at motor} \times \text{volts lost on line} \times \text{motor efficiency,}}$$

the tabulated values have been determined from the resulting formula:

$$\text{Cost} = \frac{760{,}320}{(E\text{-}V)\,V}, \qquad (1)$$

in which $E =$ E. M. F. at station, $V =$ volts lost on line; motor efficiency is taken at 90 per cent. and distance at 5,280 feet. The tabular figures give the investment. To reduce to actual cost per horse-power hour, rate of interest and depreciation, and ratio between power transmitted and power possible to be transmitted must be had. For one year the possible horse-power hours = 365 × 24. Take annual interest and depreciation at 1-16 the investment and ratio of actual to possible power trans-

TABLE IV.—FOR DOUBLE METALLIC CIRCUITS.

COPPER INVESTMENT, IN DOLLARS, FOR TRANSMITTING ONE H. P. ONE MILE.

Motor efficiency = 90 per cent.

Initial E. M. F.

Drop on line, volts.	500	1,000	1,500	2,000	2,500	3,000	3,500	4,000	4,500	5,000	5,500	6,000	7,000	8,000	9,000	10,000
100	19.00	8.44	5.42	4.00	3.20	2.60	2.20	1.80	1.60	1.44	1.40	1.28	1.10	0.98	0.84	0.76
200	13.66	4.80	3.42	2.12	1.64	1.34	1.14	1.00	0.88	0.78	0.70	0.64	0.56	0.48	0.42	0.38
300	19.00	3.60	2.12	1.50	1.20	0.94	0.80	0.68	0.60	0.54	0.48	0.44	0.36	0.32	0.28	0.26
400		3.20	1.72	1.20	0.92	0.72	0.60	0.52	0.44	0.40	0.34	0.32	0.28	0.24	0.22	0.20
500		3.00	1.50	1.00	0.76	0.60	0.50	0.40	0.36	0.34	0.30	0.28	0.22	0.20	0.18	0.16
600		3.20	1.40	0.92	0.66	0.54	0.42	0.34	0.32	0.28	0.26	0.22	0.20	0.16	0.15	0.14
700		3.60	1.34	0.82	0.60	0.46	0.38	0.32	0.28	0.24	0.22	0.20	0.16	0.14	0.12	0.10
800		4.80	1.34	0.80	0.56	0.42	0.34	0.30	0.26	0.22	0.20	0.18	0.14	0.14	0.10	0.10
900		8.44	1.40	0.76	0.54	0.40	0.32	0.28	0.22	0.20	0.18	0.16	0.12	0.12	0.10	0.08
1,000			1.50	0.76	0.50	0.36	0.30	0.24	0.20	0.18	0.16	0.15	0.12	0.10	0.08	0.08
1,200			2.12	0.80	0.48	0.34	0.28	0.22	0.18	0.16	0.14	0.12	0.10	0.08	0.08	0.07
1,400			5.42	0.90	0.48	0.33	0.26	0.20	0.18	0.14	0.12	0.10	0.08	0.08	0.06	0.06
1,600				1.12	0.52	0.34	0.24	0.20	0.16	0.14	0.12	0.10	0.08	0.06	0.06	0.056
1,800				2.12	0.60	0.34	0.24	0.18	0.16	0.12	0.10	0.09	0.08	0.06	0.06	0.05
2,000					0.76	0.36	0.24	0.18	0.15	0.12	0.10	0.08	0.06	0.06	0.054	0.046
2,400					3.20	0.52	0.28	0.20	0.14	0.12	0.10	0.08	0.06	0.05	0.048	0.04
2,800						1.34	0.38	0.22	0.16	0.12	0.09	0.08	0.06	0.05	0.04	0.038
3,200							0.78	0.30	0.18	0.12	0.10	0.08	0.06	0.05	0.04	0.034
3,600								0.54	0.22	0.14	0.10	0.08	0.06	0.05	0.04	0.032
4,000									0.36	0.18	0.12	0.08	0.06	0.046	0.038	0.032
4,500										0.60	0.16	0.10	0.06	0.04	0.036	0.030
5,000											0.30	0.15	0.06	0.04	0.038	0.030
6,000													0.12	0.06	0.04	0.032
7,000														0.10	0.054	0.036
8,000															0.08	0.046
9,000																0.008

In using the table it will be convenient to draw curves of equal cost. They will be, roughly, arcs of circles convex toward the left.

mitted per annum at 1.0, 0.8, 0.6, 0.4, 0.2, 0.1, 0.05, then the divisor of the tabular number becomes 140,160, 112,128, 84,096, 52,064, 28,032, 14,026 and 7,008 respectively.

It remains to obtain values for the distance of transmission.

Let n = number of miles of line supplied from one station.

h = horse-power required for unit locomotive.

K = maximum number locomotives per mile at any time.

$n\,h\,K$ = total power to be transmitted at time of K.

A = percentage of dynamo power lost on line.

$\dfrac{n\,h\,K}{100-A}$ = maximum power to be generated.

$\dfrac{n\,h\,K}{100-A},\times\dfrac{A}{100}$ = " " lost on line.

b = cost in cents of generating one horse-power hour in station.

r = ratio of average power required to maximum power required.

L = interest and depreciation on supporting structure.

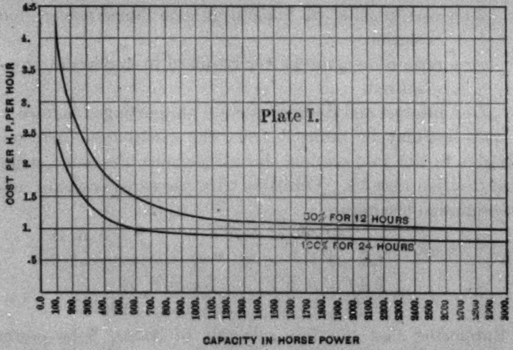
This last may be omitted from the calculation, determining division of line into section, since it remains the same, whatever that division may be. Omitting this, the expression for cost of transmission becomes:

$$\text{Cost} = \frac{760{,}320\, n^3\, h\, K\, r}{(E-V)\; V \times 140{,}160} + \frac{b\, n\, h\, K\, A}{r\,(100-A)\,100}$$

$$= \frac{5.42\, n^3\, h\, K\, r}{(E-V)\; V} + \frac{b\, n\, h\, K\, A}{r\,(100-A)\,100} \qquad (2)$$

Supposing that the time schedule of trains, horse-power required per train, and efficiency of motors be known, and that the initial E. M. F. be in all cases taken as high as the state of the art permits, the only variables remaining in this expression are n, b and A. This latter, the value for the drop on the line, will generally be determined by conditions other than those of strictest economy, as shown by getting a minimum value for cost of transmission. We must have a reasonably uniform E. M. F all along the line, in order that the motors may work satisfactorily. It will not be wide of the mark to assume 10 per cent. as a limiting variation of line potential. This is the figure generally assumed in calculating wire for street railways.

The cost of one h. p. hour b must vary with the capacity and conditions of working of the station; hence it is a function of *n*—*i. e.*, length of unit section, of *A*, and of that inexpressible variable— the conditions of the service. This stands in the way of obtaining any perfectly general definite expression for *n*, which, but for this, would result from placing the first differential coefficient of *C*, with respect to *n*, equal to zero, and solving to find the value of *n*, giving a minimum value for *C*. If trains be run at very short intervals, increase of *n* would be followed by proportional increase in capacity of station; but, as above shown, this need not go beyond 3,000 h. p. unless the service be so heavy as to require practically contiguous stations of that capacity. If we suppose a case of this short-interval service, so short that a change in *n*, will not be followed by any change at the station in the relation between maximum capacity and average output, or in the number of working hours, but only in the normal capacity, the relation between *b* and *n* for two cases of average output and working hours is shown by Fig. 1. The equation of the 50 per cent. curve from 200 to 1,000 h. p. seems to be very nearly



$$b = \frac{n^2 - 98n + 1,000}{12\,(n - 100)}.$$

If the trains be run at very long intervals, we may require no greater station capacity for 20 than for 10-mile sections; but the relation of output to normal capacity will vary, and possibly the number of hours during which the working force would require to be kept on pay.

Taking the case of a change on average output only, for a 1,000 h. p. station, we have the curves in Fig. 2, for 24, 18 and 12 hours' work. The equations are nearly of the same form, and are approximately the equations of arcs of circles referred to an origin outside the circle. But each would contain different constants, and would vary more or less from the exact formula for the circle.

If, in the application to a particular case, the algebraic expression for *b*, above given, or any other resulting from any of the possible progressions through Table III., be substituted in Eq. 2, we may, by differentiation, solve that particular case for the most economical value of *n*. If the relation between *b* and *n* cannot be algebraically expressed, then the proper value for *n* may be determined by a few trial values, the corresponding values of *b* being taken from the table.

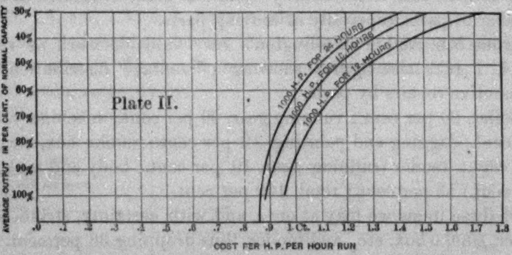


Plate II.

For the present purposes of comparison, we will assume a case not more favorable than might often be met on busy steam lines, *i. e.*, a station of 2,000 h. p. normal capacity, working 18 hours per day at 40 per cent. of its normal output, the cost per horse-power being 1.25 cents.

To obtain the cost of the line, we will assume that the average distance of transmission is five miles. This would correspond to one station for every twenty miles of road. We will also assume 5,000 volts initial E. M. F. and 10 per cent. drop. From Table IV. the copper investment is found to be 34 cents for one mile. Then for five miles the investment equals $8.50. Making assumptions as to service corresponding to those for the station, we have cost of one horse-power equaling $8.50÷20,000—0.042 cent.

The structure for carrying the conductors may be built for $2.000 per mile. Interest and depreciation would then become $200 per annum. This total is almost wholly independent of the power transmitted, hence the cost per unit of power will vary directly with the number of units transmitted. Assuming a constant distribution of one 500 h. p. train for every 20 miles of line, we have the cost of this item for 1 h. p. hour:

$$20,000 \div 365 \times 24 \times 25 — 0.09 \text{ cent.}$$

Reaching the locomotive, we must add, supposing an average output of 500 h. p., 0.08 and 0.06 cent respectively for driver and his assistant. The latter is necessary only as a substitute for his principal in case of emergency, but as such he would doubtless always be placed on trains of considerable value.

Repair on electric locomotives is not as yet well defined. That the repair bill must be far less than in the case of steam locomotives follows almost necessarily from the great reduction in the number of parts, especially of moving parts.

From Mr. Arthur Wellington's very valuable work on railways, I take the figures showing percentage distribution of locomotive repairs by parts.

Boiler, 20 per cent.; running gear, 20 per cent.; machinery, 30 per cent.; lagging and painting, 12 per cent.; smoke box, etc., 5 per cent.; tender (running gear, 10 per cent.; body and tank, 3 per cent.) 13 per cent.; total, 100 per cent.

Of these items we may at once, and with certainty, strike out boiler, smoke-box, etc., and tender, thus dropping 38 per cent. of the total. Having no boiler to carry, the running gear will be less in quantity.

The wear will be less, due to the use of rotary instead of reciprocating effort. It will then be fair to reduce this item by half, making another saving of 10 per cent. So in the machinery item, there can be no question that with the rapid advance toward slow-speed motors, reducing gearing, and sounder insulation methods, the great advantage of having only *one moving part* in the motor itself must operate to very largely reduce the repair figure, probably to half its value in a steam locomotive, leaving it at 15 per cent. In lagging and painting, the omission of boiler and other parts must again effect a reduction, say to 6 per cent. The total reduction thus plainly indicated must be then very nearly 70 per cent.

The actual cost of repairs to-day on steam locomotives is, on the P. R. R. nearly 0.75 per h. p. hour, as will later appear. Reducing as above, this figure becomes 0.22 cent for electric traction. This refers to engines of considerable power; say from 400 to 1,000 h. p. capacity. The figure for both steam and electric motors would go up for smaller powers.

The interest charge results from considering the cost of an electric locomotive as $50 per h. p. and the duty as six hours per day full capacity. The average duty of steam locomotives is only about three hours. The higher figure results from a smaller number of repairs necessary, due to greater simplicity of parts, Then

$$\text{Interest for h. p. hour} = \frac{50.00 \times 0.05}{365 \times 6} = 0.11 \text{ cent.}$$

Before summarizing we must know something of the efficiency of the system. If the locomotive be of 90 per cent., or 80 per cent., or 60 per cent. efficiency, we must generate, respectively. 1.25, 1.4, and 1.85 h. p. hour in the station for every h. p. hour actually delivered to drivers, line loss being supposed constant at 10 per cent.) We should then have in the station 1.56, 1.75 and 2.30 cents, respectively.

Then, for total:

Station.	1.56	1.75	2.30
Conductor system	0.042	0.04	0.04
Structure for same	0.09	0.09	0.09
Wages.....	0.14	0.14	0.14
Repairs..	0.22	0.22	0.22
Interest...........	0.11	0.11	0.11
Total................	2.16	2.35	2.90

Of the whole amount, it is to be noted that the station item is three-fourths. Taking the most favorable case shown by the table,—3,000 h. p. capacity, working for 24 hours at 100 per cent. of capacity—those figures become 1.5, 1.62 and 2.00 cents nearly, the reductions in the other items being still a little indefinite, without making another series of independent assumptions.

The cost of one h. p. hour, excited by steam locomotives, is to be obtained only by some circumlocution, the reports of cost being based on train-mile. As quoted by Wellington, the coal consumed per passenger train-mile on the Pennsylvania Railroad is very closely 50 pounds, and an average performance will show 5 pounds coal per h. p. hour, while *under way. This shows that one train-mile equals* 10 *h. p. hours.* The coal consumption for a freight train-mile is much higher, but the divisor would also be higher, on account of the greater number of stops, or at least of backing and switching, and greater delays while on a trip, thus increasing waste of coal.

Again, the Pennsylvania Railroad reports show cost of fuel per train-mile of 5 cents. The cost of coal to that company, as nearly as I can learn, is about $1.50 per ton. Hence it would appear that 66 pounds per train-mile are consumed. As the terminal losses of fuel and delay (getting up steam and drawing fires, etc.) are known to be in the neighborhood of 25 per cent. of the total consumption, we have 6.6 (pounds) as the divisor, and the same ratio again appears.

The cost of one train-mile—as to motor power alone—is given by the Pennsylvania Railroad as 22 cents. And this is practically equal to the average for the United States. The itemized statement is very carefully made up, and seems to cover everything except interest on the engine investment.

Knowing the annual mileage per locomotive to be about 20,000 and the cost to be $10,000, interest charge per train-mile (not quite, but nearly, equivalent to engine mile) becomes 2.7 cents. Total cost becomes 24.7 cents, or 2.47 cents per h. p. hour.

We may safely use this figure in the comparison to be made, since any positive error in the calculation of coal per h. p. hour, or negative error in h. p. hours per train-mile, will be offset by the difference in cost of coal per ton to the P. R. R. as compared with the value assumed in Table III.

At $3, instead of $1.50, the fuel item would be 10 cents and the total motive power 29.5 cents. Leaving the statistics of actual cost, we may reach, by the method of Table III., nearly the same figure, considering the locomotive as a 1,000 h. p. steam plant, of low first cost, burning 6 lbs. of coal per h. p. hour, and working at one-third capacity for about three hours per day. The result thus reached is about 10 per cent. higher, but the 2.47 cents seem most reliable.

These values multiplied into the corresponding values in the last nine columns of Table I., give the following values of:

$$\frac{\text{Power units, steam}}{\text{Power units, electric}} \times \frac{\text{cost per unit, steam.}}{\text{cost per unit, electric.}}$$

This value, Table V., being greater than unity indicates greater economy by electricity than by steam, and vice versa.

A glance at the table shows the dominating necessity of in-

TABLE V.

Ratios of cost of motive power.

Efficiency of electric engine.	10 per cent.			20 per cent.			40 per cent.		
Tonnage and area relation.	2 & 3	2 & 5	2 & 8	2 & 3	2 & 5	2 & 8	2 & 3	2 & 5	2 & 8
Speed.									
20	1.15	1.16	1.16	0.92	0.85	0.85	0.56	0.56	0.55
40	1.19	1.19	1.17	0.95	0.95	0.95	0.57	0 57	0.56
60	1.25	1.24	1.19	1.00	1.00	0.95	0.58	0 58	0 56
80	1.33	1.32	1.22	1.07	1.03	0.94	0.59	0.59	0.57
100	1.58	1.42	1.32	1.23	1.20	1.05	0.66	0.65	0.59
120	2.57	1.94	1.47	1.66	1.49	1.13	0.80	0.78	0.64
140	10.03	3.82	1.87	7.35	2.83	1.46	2.72	1.36	0.72

creasing the efficiency of the mechanism delivering energy from the electric line to the vehicle. We cannot count upon a higher efficiency than 90 per cent. for the motor. Hence, save in the case of putting the armature directly on the axle, we cannot hope to reduce the total loss to less than 20 per cent.—a case permitting one set (*i. e.*, two gears) of spur gearing between armature and axle. As the ordinary relation between tonnage and resisting area will lie between the second and third columns of each efficiency table, it appears that with a 20 per cent. loss, electricity becomes cheaper than steam at about 70 miles per hour.

In the case of 40 per cent. loss our new agent betters the old only at 140 miles per hour. And yet this loss—40 per cent.—is about the best we do with our present systems of electric propulsion. This appears from the following tabulation of results obtained by me on the Brooklyn & Jamaica Electric Railway, Table VI.

Considering the very short life of the art, these results are excellent. Indeed, excellence is shown in the mere fact of success in competing with horses under conditions very trying for any mechanism not made of india-rubber or whit-leather. How great that success has been I need not here proclaim. But the steam locomotive is a foeman more worthy of our steel, or rather of our annealed soft iron, and 99 per cent. copper.

Consideration of all that precedes leads to the following general conclusions:

1. A slow-speed armature placed on the car axle would place the electric motor in the lead at all service speeds.

2. For speeds above 70 miles per hour an electric motor of 90 per cent. efficiency, working through gearing of 90 per cent.

efficiency would prove more economical than the steam locomotive—save in cases of very infrequent service on very long lines.

3. On lines for heavy traffic, steam would be more economical than electricity if motor and gearing have a combined efficiency as low as 60 per cent., up to 100 miles per hour.

4. At speeds of 100 miles per hour and upward, neither steam at 90 per cent. nor electric apparatus at 60 per cent. efficiency is commercially practicable.

5. Inasmuch as the saving of coal in stationary, as compared with locomotive engines, is one of the chief causes of the greater economy of electric propulsion, at any speed, this advantage will increase with that difference and also with the price of coal.

6. Any cause other than inefficiency of motor which increases the power required to haul a ton of freight, increases the advantages of electricity, since it enlarges the value of the coal difference and the dead-weight difference.

Thus, bad roadways and large areas exposed to atmospheric resistance, as in street railway work, lower the speed at which electric motors of any efficiency become cheaper than steam.

7. In descending to small locomotive units, the electric motor loses less, relatively, of its advantage—another reason for success on street lines.

8. Multiplying the number of motors should be, as far as possible, avoided.

9. In special cases cleanliness and compactness of electric machinery may be of great value; in case of very frequent stops, the possibility of returning to the line the energy now wasted in brakes may be of considerable value. This, however, can be obtained only by sacrifice in the matter of dead-weight, as normal working is implied to be at comparatively low magnetization. Loss due to low efficiency in starting can scarcely be avoided either in steam or electric engines.

10. Other minor pros and cons may be enumerated, but I believe that in considering the general economic results of the two systems we reach more definite conclusions.

While only one condition of station working has been taken for final comparison, that case is an average one, and comparative results would be but slightly affected by ordinary varations Extreme cases may be readily determined from the tables and formulæ presented.

11. Some difference of opinion as to the proper values for the

various constants are to be expected, but I believe these differences, taken all along the line, would nearly balance between positives and negatives, leaving the general results and the method unchanged.

Whether these conclusions be accepted or not, I believe the tables and formulæ here presented will be found valuable.

Discussion.

The President:—I am sure we have all been very much gratified in listening to this extremely interesting paper upon a question that is certainly a live issue, if there is a live issue at the present day. We should be glad to hear any remarks upon it. The paper is now before you for discussion.

Dr. Louis Bell:—I wish to state one point in addition to what Mr. Crosby has mentioned in his very exhaustive paper, and that is that the electrical difficulties with which we have to contend in street car work, which have made it so difficult for electricians to get good efficiencies and low repairs—nearly all disappear when we come to these high speeds, due to the fact that we can put the motor directly on the axle, doing away with the gearing, which, as you say, involves a loss of 40 per cent. in efficiency. Furthermore, with the powers required, that is from 400 to 1,000 horse-power, there is no sort of difficulty in building the motor of a higher efficiency, and at the same time putting it directly on the axle, the speed required to drive an express train from 40 to 60 miles per hour, being in a general way from 500 to 550 turns a minute, which for a motor of the size involved is not a necessarily low speed. A 400 horse-power motor would naturally be made to run somewhere near 500 revolutions—not much in excess of that—so that there arises no difficulty in placing the motor directly on the axle, a condition which can at present be fulfilled, if at all, only with immense difficulty in street car service. The electrical difficulties, therefore, very largely disappear for the reason that the motor required for express service upon railroads would be so large that it could be made to run at as low a speed as is required for express service and at the same time have a high efficiency. I do not think that any man who is used to the designing of large electrical machinery would hesitate to design a four pole machine to reach 500 revolutions and develop 400 horse-power at an efficiency of 85 per cent. which would give electricity an equal chance with steam. Furthermore at these speeds with large motors they will not be placed under the car in the dirt and dust and wet, but will be placed where they can be protected, so that there is no reason apparent on the face of it why a 300 or 400 or 500 horse-power motor should not be operated with the same efficiency, with the same freedom from repairs, with the same ease as we now operate large dynamos in a central station.

FIGURES ON STREET-CAR

Date.	Designation of motor-car.	Weight of motor-car and passengers.	Weight of towed car and passengers.	Length of trip in miles.	Average speed, miles per hour.	Potential at station, volts.	Ditto at car, average.	Current in motor "A," amperes.	Current in motor "B."	Current in trolley wire of car.	Difference of "A" and "B."	Number of readings averaged.	Corresponding time interval, seconds.	Total average energy in [illegible] in H. P.
April. 3	No. 6	Pounds. 12,000	0	3.5 and return, 7.0	9.3	480	440	6.63	6.63	13.27	A and B assumed equal except when difference was measured.	[illegible]	[illegible]	[illegible]
3	6	12,000	0	2.84 and return, 5.78	10.45	480	440	7.6	7.6	15.2		[illegible]	10	[illegible]
3	8	12,000	0	2.84 and return, 5.78	11.5	480	440	11.85	0	11.85		[illegible]	12	6.96
3	8	12,000	0	3.5 and return, 7.0	9.1	480	440	10.0	0	10.0		[illegible]	12	[illegible]
20	8	11,850	6050	2.84 and return, 5.78	10.0	480	440	7.85	7.85	15.7		[illegible]	15	[illegible]
20	8	12,000	7200	2.84	8.3	480	440	12.26	0	12.26		[illegible]	[illegible]	[illegible]
May 2	8	12,400		2.84 and 3.5 6.34	10.9	480	440	7.68	5.52	14.2	1.16	[illegible]	[illegible]	[illegible]

NOTE.—Voltmeter readings taken April 3 and 20, assumed same values May 2. Traction not been determined for wide ranges of condition by shop tests. Values for hysteresis, etc., with a low current, a very large armature induction is effected. The "R" in C²R cannot be vation. Total error in motor losses probably not greater than 10 per cent. Run No. 7 not intro

Average
"
"
"
"

TABLE VI.

CAR TRACTION. TRACK NEARLY LEVEL.

[illegible]	[illegible]	Corresponding mechanical H. P.	Hysteresis, eddy currents and friction in armature "A," watts.	Ditto in armature "B."	C^2R loss in "A," watts.	Ditto in "B."	Total loss in motor or motors, H. P.	Total gearing loss, H. P.	Efficiency of motor or motors.	Ditto of gearing, one or two sets.	Ditto of motors and gearing.	Record number of run.	Remarks.
[illegible]	27.3	4.09	550	550	88	88	1.71	1.83	77.4	69.0	53.6	1	Track this day rather dirty. Tonnage co-efficient taken 10 per cent. higher than Apr. 20. when observations were made.
[illegible]	27.3	4.6	600	600	115	115	1.97	2.4	78.0	65.7	51.3	2	
6.96	27.5	5.06	675	0	230	0	1.2	0.7	82.7	87.8	72.7	3	Armature of motor "B" taken out for this and trip No. 4.
5.87	27.5	4.0	550	0	200	0	1.0	0.87	83.1	82.1	68.0	4	
[illegible]	25	6.0	600	600	123	123	1.94	1.31	79.0	82.0	64.8	5	Dynamometer between motor and tow car, 131 readings taken.
[illegible]	[illegible]	5.31	500	0	300	0	1.07	0.85	83.2	86.0	[illegible]	6	Motor "B" cut out of circuit
[illegible]	[illegible]	4.5	650	650	118	61	1.98	1.89	76.3	70.4	[illegible]	7	Separate ammeter in each tor circuit and in main.

April 20, as track was in same condition. Losses in motors cannot be given with perfect accuracy, as they have y with several shop tests. Except C^2R, motor loss does not vary largely with current flowing in practice, as constantly changes with change in position of switch. A fair average of switch position was obtained from obser- difference of action of motors "A" and "B:"

two motors = 55.9 per cent
one motor = 71.2 "
.... = 83.6 "
.... = 77.6 "
.... = 71.8 "
.... = 85.3 "

Mr. F. L. Pope:—In my opinion the high-speed locomotive of the future will not be managed by an intelligent man who goes with it, but will be handled from the ground by men placed at short intervals along the line to guard against obstructions of all kinds, and who will be able simply by taking a pair of nippers and cutting a small wire running along the track to bring any train to a stand on any section in a few moments automatically, if they discover anything the matter with the track or any obstruction in the way. It is rather difficult to imagine what an engine-man, going at that rate of speed, would be able to do if he did see anything in the way, because he would get to it almost before he saw it.

Mr. Crosby:—I might say the presence of a man on a locomotive is of less value for taking care of accidents due to a possible obstruction on the track than for handling the locomotive at starts and stops. I am aware of no way of making an electric engine start and stop properly without some form of wasting energy, either an external resistance or some compensation of internal resistance amounting to practically the same thing, and somebody has to exercise intelligence in doing that. It can be done, and I have done it from the station. I have sent a car at a high rate of speed without any one on it, because the track was not a fit one to travel on, and we managed it very well with nothing but a water barrel as a rheostat. But probably there is no reason why a man should not sit on the locomotive and operate some electrical controlling device. As for obstructions they will have to take care of themselves, or the track will have to be well fenced in. I see no way of ameliorating that trouble except by keeping the tracks clear.

Prof. Thomson:—I would like to add one word in regard to keeping the track clear. It is a question, in my mind, whether a locomotive of that kind would not keep the track clear itself. You have all heard of the experiment of shooting a candle through a board. I have fired wax bullets through a board with an air gun. The wax bullet was found imbedded in the board at quite a depth and in perfect shape; so we may consider perhaps that in getting the locomotive in the proper shape at the end so as to get rid of all obstacles it will get along very well. (Laughter.)

Mr. Joseph A. Miller:—I see that the subject of this paper is limitation of steam and electric transportation. Now limitation in that sense is similar to a limitation of how far you can see. It is a limitation as far as we can see now. Now, I have lived quite a length of time. I have seen the development of steam railroads, the introduction of gas, of electricity, etc., and what were limitations five or ten years ago are not limitations now.

What must we do to increase our speed? Well, the first thing we must do is to reduce our dead weight so as to have a larger paying weight.

How can we do it?

The locomotive's enormous weight is a destruction to the tracks; again, the increase in the length of cars demands greater weight and greater strength on account of the greater length they have to support. Do away with the locomotive first. It is an enormous expense, an enormous weight, etc. The next thing is to support your cars the whole length so that you do not have to bridge-truss them.

How?

Knock out these running gears and put them on skids.

MR. CROSBY:—I can only be gratified at the slight misunderstanding, since it has brought out such an entertaining dissertation on the matter. I mean limitations as compared each with the other. I do not mean to say that I have fixed a limit.

PROF. W. L. HOOPER:—I was much interested in what Mr. Crosby had to say in regard to resistances at high velocity. Some time ago I looked into the subject somewhat, and the ordinary values for the co-efficient seemed too high. The velocities, however, were very high. I obtained the result of careful tests made on the projectiles of the new eight-inch rifles for the United States Navy and at the various velocities given, the resistances were roughly proportioned to the square of the velocity, but the co-efficient was much smaller than is commonly used in engineering. But it may perhaps be interesting to know that velocity at a little less than 2,000 feet per second, the horse-power expended in overcoming the air in the case of a projectile weighing 300 pounds was nearly 3,000 horse-power. That is a velocity of 23 or 24 miles a minute—1,400 miles, say, an hour.

MR. CROSBY:—Referring to the matter of atmospheric resistance I can only repeat a good deal of what appears in the paper I have written on the subject, and which is now in print. The law of variation of velocity is a changing law and at times the variation is as high as with the sixth power of the velocity. The high values attained in ordnance gives us a succession of changing exponents for V. Starting with V^2 at the lowest ordnance velocities, which, however, are very much higher than anything we call engineering velocities, that exponent increases to the sixth power, and that very high rate of change holds over a short range of velocity from about 1,300 to 1,700 feet per second, perhaps. Then there is a gradual diminution in the exponent, and at the highest attained velocities in ordnance experiments the square again is found to be the exponent of V. But the demonstration I made, carried the velocities nearly to the lower limit of ordnance velocities above the present range of engineering velocities, and in that range, the variation, so far as anything can be detected in quite an extended series of experiments, is a rectilinear variation, but it is because the exponent is found to be so variable a one that I feel it rather strengthens the position I have taken. Save for the authority of absolute experiment over any range of velocities there is no proper guide for determining the pressure with respect to velocity.

PRACTICAL ASPECTS OF THE ALTERNATING CURRENT THEORY.

DISCUSSION OF DR. M. I. PUPIN'S PAPER AT THE GENERAL MEETING, BOSTON, MAY 21, 1890.

(*See page* 204 *ante.*)

The President:—We would be glad to hear any remarks now upon this very interesting paper.

Mr. Crosby:—I would like to ask whether Dr. Pupin finds that it is really a simple matter to design an alternating motor as compared with the work of designing a continuous current machine. While the general theory may be expressed with almost equal simplicity, will not the introduction of those mathematics, the value of self and mutual induction, make it a more difficult matter to design an alternating than a continuous current machine?

Dr. Pupin:—Well, not being a practical man and never having designed an alternating current machine or a continuous current machine, I, of course, could not answer that question.

Prof. Thomson:—I should say that having designed both continuous and alternating machines, I see no particular difficulty in doing either; there are certain things that are left out altogether in the design of alternators which have to be considered in the designing of continuous current machines, as in the commutation. Of coure the simplest forms of expression will not take in all the little attentions that have to be given in that direction. So it is with the alternator we may say that there are some things to be attended to which are not taken in in the simplest forms of expression, but so far as I can see I should say that the problem is not more complex than that of designing a good continuous current machine.

The President:—I understand that the experiments which are to be taken up in the next paper require the use of the steam engine and that steam is being kept up for us, and I think we had better pass on to the next paper and resume this discussion later. There will be an opportunity for continuing this discussion after the reading of the paper by Mr. Lemp on automatic electric welding machines.

A paper read at the General Meeting of the American Institute of Electrical Engineers, Boston, Mass., May 21st, 1890.

AUTOMATIC ELECTRIC WELDING MACHINES.

BY HERMANN LEMP, JR.

AMONG the latest achievements in electrotechnics, stands prominently Prof. Thomson's electric welding process. The broad underlying principle has so often been described and exhibited by its able discoverer and others, that to repeat it now would be imposing upon your patience. The evolution of a new process and its reduction to practice for commercial purposes, especially if the leading elements of its working are novel in themselves, must necessarily open a vast field for investigation. Such is the case with electric welding, and with a view of showing the commercial apparatus of to-day, it will be necessary for me to state the electrical and mechanical requirements which led to its construction.

The reason for which machines have been invented has been for the purpose of reproducing faithfully and constantly a set of conditions necessary to obtain a certain result. When the conditions in any case are few and the product simple, generally one design of machine will be sufficient. With an increased number of conditions, however, the complexity of the apparatus increases rapidly and demands, in many cases, a subdivision into different processes to be executed by separate machinery. What constitutes skill in a workman, for instance, is the ability to coordinately reproduce a number of operations or movements; to be, in other words, a perfect machine, or to produce the same result even if other conditions than those previously contemplated should arise.

To secure uniform results in the practice of a difficult operation, there are two ways possible.

1. To employ skilled help for the complex portion of the work alone.

2. To substitute for the more complex portion of the operation one more readily controlled.

The ordinary welding process requires the greatest skill at the hands of the blacksmith for heating the metals to the proper temperature and at the right spot, while preventing the accumulation of cinder or scale. While skill may be successful with metals of high melting points and low conductivity for heat, easily fusible metals and specially good conductors baffle all attempts as long as an exterior heating source is employed.

The electric welding process has, as you know, not only made it possible that operators not particularly skilled in the art of blacksmithing can produce good substantial welds, but has created an art equally adaptable to all metals and combinations of metals.

The following are all the metals, alloys and combinations so far actually welded with success by the Thomson process;

Metals.—Wrought iron, cast copper, antimony, aluminum, manganese, cast iron, lead, cobalt, silver, magnesium, malleable iron, tin, nickel, platinum, wrought copper, zinc, bismuth, gold (pure).

Alloys.—Various grades of tool steel, various grades of mild steel, steel castings, chrome steel, musshet steel, stub steel, crescent steel, bessemer steel, cast brass, gun metal, brass composition, fuse metal, type metal, solder metal, german silver, aluminum alloyed with iron, aluminum brass, aluminum bronze, phosphor bronze, silicon bronze, coin silver, various grades of gold.

Combinations.—Copper to brass, copper to wrought iron, copper to german silver, copper to gold, copper to silver, brass to wrought iron, brass to cast iron, tin to zinc, tin to brass, brass to german silver, brass to tin, brass to mild steel, wrought iron to cast iron, wrought iron to cast steel, wrought iron to mild steel, wrought iron to tool steel, gold to german silver, gold to silver, gold to platinum, silver to platinum, wrought iron to musshet steel, wrought iron to stub steel, wrought iron to crescent steel, wrought iron to cast brass, wrought iron to german silver, wrought iron to nickel, tin to lead.

But Prof. Thomson was not satisfied with this progress made above ordinary welding, and early recognized the importance of a machine in which all conditions for successful operations are mechanically controlled to produce uniform results, and which would be rapid working and require little or no attendance.

Such machines now known as automatic welding machines, have proved to be of special importance in connection with easily fusible metals, enabling the successful welding of aluminum, silicon and aluminum bronze, which, even with the electric process, require considerable skill.

Before entering into a detailed description of the automatic welder, a few general data on welding will be in order.

The Thomson process of electric welding can be, and has been, worked by means of continuous or alternating currents; secondary batteries or multipolar machines may be and have been used. There are such conditions as transportability, absence of motive power, situation in continuous distribution district, etc., which may make it advisable to use the continuous current. The alternating currents have so far been the best adapted to be produced economically of large volume at low E. M. F. They are easily and economically controlled, allow of being distributed at high pressure with small conductors and of being reduced to working pressure wherever needed. They have, however, another beneficial effect, which is of importance in all welds of large sections.

It is a well-known fact amongst manufacturers of incandescent lamp filaments of large section that the inner portion in a filament is apt to be overheated. In treating filaments as used in the now commercial series lamp, in a hydro-carbon atmosphere, the writer attempted at one time to produce an extra good quality of carbon by starting with an extremely thin base .004 inch thick and obtaining a filament, 90 to 95 per cent. of which consisted of hard, gray, lustrous carbon. He thought to extend this process to the manufacture of arc light carbons and even produce pencils of about ¼ inch diameter. What was his surprise, however, to find that although the lustrous surface presented at times a dense gray structure, the core lost this character after a certain thickness of carbon had been deposited. In fact, a number of concentric layers could be discovered from the innermost graphite to the dense gray semi-crystalline at the outside.

This action can, to my mind, only be attributed to the overheating of the carbon particles in the inside. A similar action takes place in a bar of iron if heated by an electric current. The surface exposed to radiation will be at a lower temperature than the core. It is true that the heating of the metal will increase its resistance and thus tend to equalize the temperature, but not enough in all cases. By the use of alternating currents we gain, however, an assistance in the self-induction. The effect of the latter is especially marked and has a tendency to concentrate the heat on the surface.

If there is any place which receives more current than another the effect of the self-induction is emphasized by the fact that the surrounding part is cool and its permeability is greater than the part traversed by the surplus of current. With very large, and especially wide, metal pieces the unevenness of distribution may be remedied by approaching iron masses to create at a given spot a greater self-induction or counter E. M. F., thus diverting the current from that section. Prof. Thomson has early recognized the importance of, and patented, a device to prevent the heating of the metal at a given spot by creating locally increased self-induction or magnetic effects.

In view of this experiment almost daily witnessed by us, it is interesting to note the paper controversy between parties disputing the priority of a device which is to produce exactly the opposite result with, however, the same means and conditions.

Two methods of distribution are in use, the direct and the indirect. In the former, an alternating current dynamo is used, having two windings on the armature, one of which furnishes currents rendered continuous by a commutator to excite the field magnets, and is controlled by switch and rheostat; the other consisting of a single turn of heavy copper cable furnishes the welding currents, which is led through collector and brushes to movable copper clamps suitable to receive and guide the welding specimens during the operation.

In some other forms the field magnet is the movable part, in which case no heavy currents have to be carried through collector and brushes. No direct welders are built at present for currents larger than 4,000 amperes.

The indirect method of distribution is almost exclusively used to-day. It consists in its simplest form of one alternating current dynamo, self or separately excited, and one welder which is a transformer with the necessary clamping and operating appliances. The self-exciting dynamos used are from 1,000 to 20,000 watts output, and may be regulated by means of a reactive coil to give a varying E. M. F. never exceeding 300 volts.

They are substantially built to withstand sudden strains, have self-oiling bearings; the brushes are designed never to be moved and are perfectly sparkless, requiring no other attention than cleanliness.

The winding on the transformer being set once for all, variation in the E. M. F. has to be obtained either by varying by hand the initial E. M. F of the dynamo or by exciting a dynamo to the lowest potential required, it being so compounded as to give with the maximum work the increased E. M. F.; or finally to maintain a constant E. M. F. at the dynamo under all loads and vary the E. M. F. at the transformer by interposing a variable resistance, or preferably a self-inductive resistance. The transformer itself may be built so as to give a different ratio of conversion, either by moving the primary and secondary relatively to each other or by shunting lines of force by means of an iron bridge between primary and secondary, or by altering the number of turns in primary or secondary by a switch.

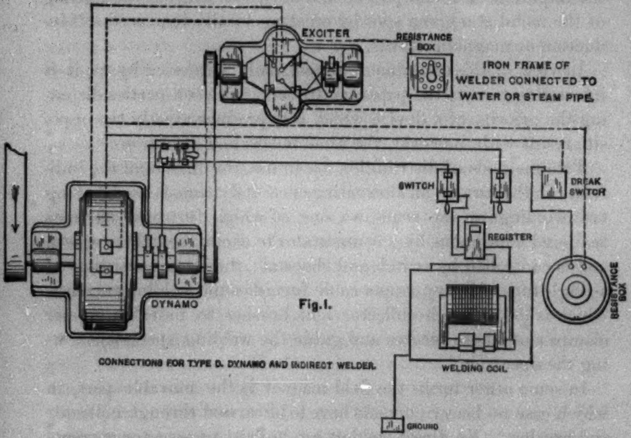


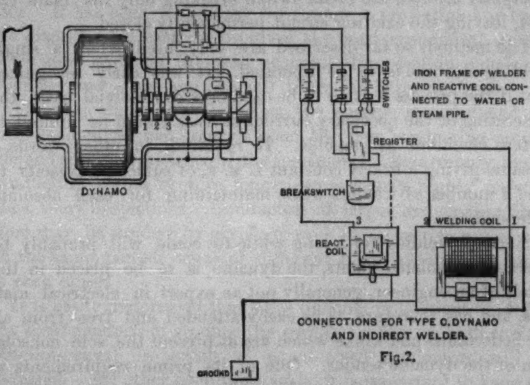
Fig. 1.

CONNECTIONS FOR TYPE D. DYNAMO AND INDIRECT WELDER.

When a single plant is used, viz., one dynamo and one welder it is the dynamo, generally, which, if separately excited, is regulated by means of a rheostat in the exciter circuit, or by a reactive coil in series with the exciting coil on the armature if self-excited. The diagram, Fig. 1, shows the connections used with a separately excited machine. The only thing different from similar installations is the break switch which is operated by a foot treadle and automatically opens the circuit when the foot pressure is removed.

This prevents any mishaps when operated by uninitiated persons, as all action ceases when one leaves the apparatus. The primary voltage never exceeds 300 volts with 100 alternations, or 50 complete cycles per second. Nothing but the very best insulation is used in the primary wiring. It is deemed necessary to protect users of the apparatus not only against any shocks, but even against the scare of one, and we recommend the permanent grounding of the secondary which in welding apparatus is virtually the table and pressure devices.

Fig. 2 shows the connections used for a self-excited composite dynamo, which has two windings on the armature, a longer main and shorter exciting coil. Both are wound in the same direction, and currents generated therein pass in multiple, connected through the shunted field magnet; after this through line No. 2, controlled by a break switch, and then split, one returning through reactive coil and line 3, the other through welder and line 1 to their respective windings. The exciting effects of each circuit add themselves. The reactive coil is conveniently placed near the welder. Dynamo is regulated from the minimum to 300 volts and is excited anew for each weld.


1 2 3
DYNAMO
SWITCHES
IRON FRAME OF WELDER AND REACTIVE COIL CONNECTED TO WATER OR STEAM PIPE.
REGISTER
BREAKSWITCH
3
2
WELDING COIL
1
REACT. COIL
GROUND

CONNECTIONS FOR TYPE C. DYNAMO AND INDIRECT WELDER.

Fig. 2.

For some work which requires to be done at great speed, the second method is resorted to; that is, to keep the field constantly excited by fixing a variable reactive coil in a given position, just enough to produce about 150 volts, the lowest E. M. F. required. The proportion of the field magnets, the E. M. F. of exciting coil and the resistance of a shunt to the field are such as to produce an overcompounding of 100 per cent. in this case, with the largest current in the primary.

This method of regulation is very neat, as it is absolutely automatic, responds quickly, the field of the dynamo not requiring to "build" every time from residual magnetism alone. We sometimes call it "cubic compounding," as it produces a constant heating effect for variable cross sections and variable lengths as well. With this modification, the wiring of diagram, Fig. 4, is slightly altered, the break switch breaking only the main circuit, leaving the exciting circuit permanently closed.

The methods so far described are only used when a single welding machine is to be operated. It was early recognized that if the process is at all to be used on a commercial basis, the generating of the necessary current at least should be limited to as few machines as possible. It required, in other words, a dynamo giving a nearly constant E. M. F. of sufficient capacity to feed a number of welders while maintaining for each absolute independence.

Since all welding for a long while to come will probably be operated in isolated plants, the dynamo is to be placed in the hands of an engineer, generally not an expert in electrical matters, and has, therefore, to be easily attended and free from all the little faults and kinks which are at present the sole consolation of the dynamo tender. One of its prime requirements is close automatic regulation under all loads.

Constant potential, self-regulating dynamos are manufactured in various sizes and are self-exciting up to 30,000 watts output. Dynamos with larger output are separately excited, but also self-regulating. The methods employed to obtain regulations are novel and will form the subject of another paper at some future date. I would simply state that either constant potential, or a percental increase with load can be obtained and that the regulation will respond even if the load consists of self-inductive translating devices. I lay some stress on the regulation of the dynamo for the reason that the generators are not to be placed in the hands of special attendants as in case of a central station, but have to deliver their currents under constant pressure whatever may be the conditions of work they are subjected to; even an automatic regulator would hardly be able to follow the rapid variation of load.

The following conditions influence the perfection of the work and are variable with different material and sizes:

1. Projection of the abutted pieces in the path of the current.

2. E. M. F. of welding current as controlling the strength of current flowing.

3. End pressure applied to force the abutting ends into each other at welding heat.

4. Interruption of current at proper time.

1. The projection of the abutted pieces varies with the diameter. It has been found that for copper, a projection for twice the diameter for each clamp gives the most economical results. With steel and iron, the most economical projection equals the diameter and is one and one-half times the latter for brass.

The projections sensibly affect the energy required and the most economical one depends upon the heat conducting properties and specific resistance of the specimens. Accordingly, highly conducting bodies require longer projections; highly resistant ones, short projections. Conductors of larger and smaller diameters may be welded by giving to each its respective projection. In the same manner wires of different materials may be joined to each other.

It is easily understood that since unequal projections on different sized conductors produce the proper heating of both at their junction, equal projection of equal sized conductors will be required. All other conditions aside, it is important to keep the projection for a given size and material constant.

2. The E. M. F. required depends upon the projection and the resistance of the material to be welded. For large cross sections the specific self-induction plays an important role, and indirectly, the shape of the specimen.

Another factor affecting the E. M. F. is the resistance between clamps and material and the resistance of copper conductors. The E. M. F. required for iron and steel is nearly double that for copper and would be four times if equal projection were used for both.

A certain drop of E. M. F. will be found from the clamps to the specimens. This drop is rather low on material having naturally bright surfaces, as, for instance, copper, brass, german silver, tin or even cold rolled iron and steel. For a large class of work, however, especially in carriage hardware, the surfaces to be used for contact have a slight scale left after passing through the rolls, which has either to be removed by grinding or filing, or to be overcome by the E. M. F. of the current. In a good many cases the introduction of a special process of cleaning is deemed to be more expensive than to use a little extra power to work through the scale.

3. For uniformity of results the end pressure required to press the abutting specimens into each other at welding heat is of more importance than any of the former agencies; this is, in fact, the one which controls and rectifies any inaccuracies in the former conditions. If the pressure necessary for a given size and material is used, the weld cannot be performed until the metal has acquired the necessary plasticity to yield to the pressure. If for one reason or another, the E. M. F. and, consequently, the current should have been too strong, the time necessary for welding alone is affected, and in this case shortened. The bars will, however, be united at the same temperature and with the same force, whatever may have been the time required to bring about the necessary plasticity. The pressure will in some respects influence the heat by forcing the metals into each other at either higher or lower temperature, and by so doing cause the action to be interrupted at an earlier or later period as may be required.

The pressure required varies with the material and is approximately 1,800 lbs. per square inch for steel; 1,200 lbs. per square inch for iron; 600 lbs. per square inch for copper; it varies also with the area of cross-section as indicated by its being expressed in a function with the surface as one of the factors.

4. The interruption of the current as soon as the weld is completed is important for all easily fusible metals. When two copper wires are welded together the welded portion being increased in cross-section owing to the end pressure, if the current is not interrupted a large portion of the conductor on either side of the weld, including the latter, become heated and will melt and be torn asunder before any pressure device could follow and bridge the gap over.

The current should, therefore, be interrupted as soon as the weld is completed. It is also sometimes required that the parts to be welded should be of a certain predetermined length, in which case the interruption of the current as soon as the allowable distance has been reached is essential.

All these conditions are maintained constant in the automatic welder before us, which is the first commercial type of its kind. This welder is not entirely automatic in the strict sense of the word. The degree of automatic action has to be considered separately for each individual object. This machine contains, however, the leading features as covered by Professor Thomson's patent, June 26, 1888, No. 385,022, with a few improvements in mechanical construction.

The capacity of the machine is, nominally, copper wire, No. 6 to No. 17 A. G. It will, however, weld larger and smaller sizes. It weighs 130 pounds complete; the secondary is one solid copper casting of a cross-section resembling a hollow, square box with one of the sides removed. This casting is firmly screwed to an iron table. A saw cut at right angles to the plane of loop creates the two poles, one insulated from the table, the other constituting a V-shaped bearing suitable to receive a sliding clamping device. The hollow part of the secondary receives the primary coil which is separately wound in a form and insulated with special care. Two U shaped laminated iron cores embrace the primary and secondary.

Fig. 3

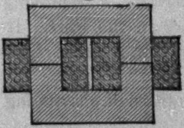
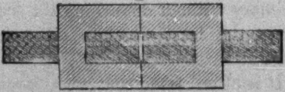


Fig. 4



It has been found that the best form of transformer is the one in which the primary and secondary coils are co-axially placed in an iron core, so as to oblige all lines of force generated by the former to cut through the latter. If the two windings are placed side by side on an iron core or on opposite legs, as shown in Fig. 3, there is a tendency to form consequent poles at the point where the two windings meet, due to the leakage of lines of force. The leakage will depend upon the distance between the two legs, and upon the length of the magnetic circuit. It has been purposely increased and turned to advantage by Prof. Thomson, for obtaining constant current in the secondary, while the primary is supplied with constant E. M. F., as shown in Fig.

4. When, however, constant E. M. F. in the secondary is required, it is important that this leakage should be decreased to a minimum.

Various forms of secondary may be employed to work consistent with the above principle. A few of these are shown in diagrams Nos. 5, 6, 7 and 8, in which cases the secondary is preferably a solid copper casting. The forms shown in Figs. 8 and 9, however, permit hard rolled copper plates to be used.

Fig. 5

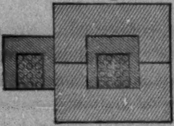


Fig. 6

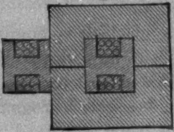
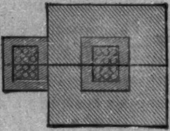


Fig. 7



For mechanical reasons and convenience, the forms shown in Figs. 5 and 6 are mostly used, and actual experience shows practically no leakage. This construction permits of removing the primary without disturbing the secondary in the least. It also gives the least possible self-induction for a given cross-section.

Fig. 8

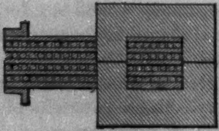
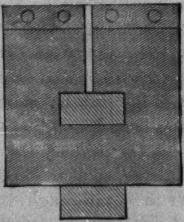


Fig. 9



It is often stated that when large quantities of alternating currents have to be conveyed through copper conductors, it is important to have the same laminated or subdivided in smaller conductors to reduce self-induction. This may be true to a certain extent. The shape of the cross-section is, however, far more important than the lamination. An experimental compound conductor consisting of a number of flat copper ribbons in parallel showed a self-induction of *three* when the ribbons were closely packed, of *two* when separated into two parts, and *one* when spread open like a fan. The explanation for this was given to the Institute last year by Prof. Thomson when he showed the self-induction to depend mostly upon the length of the lines of force surrounding a conductor when traversed by intermittent or alternating currents.

Returning to the subject before us we find that the pole which is insulated from the table constitutes the stationary clamp. The uninsulated pole, which is considerably larger, has on its upper side a long V-shaped groove parallel with the axis of the secondary, Fig. 10. A movable copper block, also V-shaped, fits in the bearing and can be slid forwards and backwards in the same.

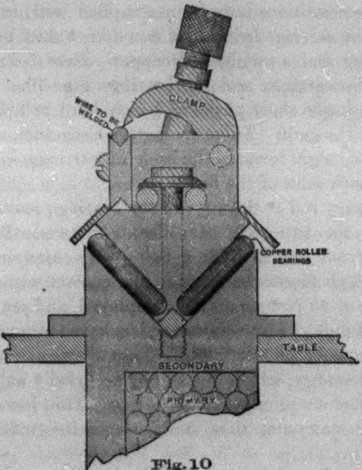


Fig. 10

This movable block carries the second clamp. The current necessary for welding has to pass through this sliding contact. The welding of small copper wire or any other easily fusible metal, is a very difficult thing if special apparatus is not used. The current required is very large, several hundred amperes for wire not larger than No. 17 A. G.

The metal when it reaches welding heat readily melts away and has to be followed by the movable clamp so as to prevent the breaking of the circuit. This latter action when it occurs, is so violent that a special device is necessary to prevent injury to the coil in case of such a rupture. The moving clamp, in order to follow the softening of the metal has therefore to have as little friction as possible and yet has to make a good contact to carry the heavy currents. The clamp is furthermore required to move in true guides so as to abut the small conductors with their axes in line. The heating necessarily brought about when rapid and continuous welding is done must not interfere with the bearing and cause the carriage to stick through expansion.

All these conditions have been complied with in using the V bearings, the carriage being held down in contact by means of a heavy spring and a number of copper rollers being interposed between the carriage and the bearing. Fig. 10. The copper rollers are simple short pieces of ¼ inch hard rolled copper wire rounded at the ends. There are sixteen altogether, eight towards the front and eight towards the back of carriage, equally distributed on both sides of the bearing.

A stationary rod at the apex of the bearing prevents the interference of the two rows of rollers. Between the two sets of rollers in front and in back, a bolt passes, applying the spring pressure which forces the carriage into contact with the bearing. A pressure of 40 pounds may be employed, and yet the carriage wiil move freely. These sixteen rollers have to transmit a current of approximately 3,000 amperes. They absorb about 20 per cent. of the total energy, which loss is, however, fully balanced by the reliability and simplicity of the device. This loss is moreover only on the maximum sizes and becomes insignificant on small work.

An adjustable coiled spring pulls the sliding clamp towards the stationary one. In front and pivoted on a lever is the distance gauge which may be inserted between the two clamps. This gauge carries on a central disk a number of steel pins of varying lengths, but equal projection on either side of the disk. These projections, if inserted between the two clamps, give the necessary distance required for a given size wire, the disk against which the wires are abutted insuring equal projection of both ends to be joined. On the back of the apparatus a switch is located in a primary circuit, which is normally held open by a spring. By moving the handle to the right, the primary will be closed and the switch locked by a little catch underneath the table. A pin fastened to the movable clamp will lift the catch and release the switch, thus opening the circuit.

An intermediate lever between catch and pin operated by a sliding rule, which serves also as an index, permits of varying the point of cut-off, which has to be in a certain relation to the distance between the clamps. The position of cut-off, tension of spring, distance between clamps corresponding to each other, are marked with the same figure. which is also inscribed on a wire gauge fastened to the welder. By inserting a wire into the gauge, the number read will give the necessary adjustments at once.

If by imprudence, the switch should be moved to the right, while no stock is inserted and the clamps come in contact with each other, the switch cannot be locked and the fuse in the primary will be blown, without, however, causing any damage.

The insertion of the distance gauge between the clamps locks the switch so that the primary can only be closed after withdrawing the gauge.

The operation is as follows:

1. The wires to be welded are gauged.
2. The distance gauge and cut-off are set to correspond with the number on the gauge.
3. The movable clamp is moved to the right and the gauge inserted.
4. Both wires are securely clamped, care being taken to abut the ends squarely against the disk.
5. The gauge is withdrawn.
6. The switch is moved to the right.
7. The reactive coil is moved towards a position of minimum reaction, and restored to maximum after the weld has been completed.
8. The clamps are opened and the weld removed, after which the operation can be repeated.

If a good many welds of the same sized material are to be made, the reactive coil may once for all be set in a given position and the switch alone be operated. Welds made with the automatic machine have attained a uniformity not obtainable with the most skilled operators working without it. In fact, small, easily fusible wires can scarcely be welded with certainty with ordinary apparatus. For aluminum, especially, the automatic apparatus is needed.

The reactive device used in connection with welders is of the type recently described by Prof. Thomson, in which a case is made to more or less cover the primary, the self-induction of which is to be altered. To obtain a still larger range, the windings of the primary can be coupled in series, or multiple series, or in multiple by a switch in the base of the coil.

As mentioned before, the welding of easily fusible metals may sometimes cause a rupture of the secondary circuit, which, owing to its violence and volume of energy may cause a burn-out of the primary if not guarded against. This danger is not very great in the automatic machine, since the end pressure does not depend upon the attention of the operator. A special device is, however, used as an extra precaution against all emergencies.

Breaking a high tension circuit rapidly is not easily done. An arc generally follows the break, and this lengthens the time of the rupture. If the voltage of the circuit to be broken is so low that over the slightest distance an arc cannot follow, the break will be instantaneous. This is the case with the secondary circuit of a welding transformer. The voltage being ordinarily only one volt, even if increased ten-fold, would not be able to maintain an arc. However, multiplied in the primary it will cause E. M. F. sufficient to pierce through the insulation as ordinarily used. This action is similar to that of a Ruhmkorff coil in which the interrupter is caused to break under oil or water. This discharge is taken care of by a special apparatus, the description of which I reserve also for another communication to the Institute.

While the machine before us is only one type embodying the principal features contained in all, others have been manufactured or are in process of construction in which the automatic character has been carried out even further, as in the welding of rings and chains. I am not permitted to give a detailed account of these latter at the present time, but would say that the present model in its first form, is able to produce 250 feet of chain in a day without any attendance to speak of, the plain wire being fed into the machine at one end and the complete chain coming out at the other.

The automatic principle is, however, not confined to small conductors. We have welders with 40,000 watts output, capable of welding 1 inch copper or 2 inch iron, constructed and working daily on that plan. The projections are determined by adjustable stops, the pressure, the most important of all, is hydraulic, and regulated by an automatic reducing valve, the exhaust being used for cooling the clamps at the same time. The primary is controlled by adjustable reactive coils from a constant potential circuit, and is interrupted at the proper time by the clamps. While not all machines are to-day operated on this plan, I am convinced that the evolution of the welding process tends in that direction, and that the welding in future will be in the full sense of the word a purely mechanical operation. This cherished idea of Prof. Thomson's, uttered a few years ago, has well been borne out by the experience gained in actual operation on a commercial basis.

DISCUSSION.

Prof. Thomson:—There is just one remark I would like to make, and that is, that Mr. Lemp is entirely too modest to put in any claims for his own work in relation to this matter. But I can say that he has worked diligently and faithfully in all the details of designing dynamos and proportioning the various arrangements, and has done a vast amount of very successful work, and I should like to testify to it here before the Institute.

The President:—It seems necessary to postpone any further discussion of this paper at the moment, as there is here a paper by Mr. Lockwood which will be read by the Secretary.

Mr. T. D. Lockwood's paper on "The Industrial Utilization of the Counter Electromotive of Self-Induction" was then read. (*See page* 226 *ante.*)

The Secretary:—Before closing, I move a vote of thanks to the authorities of the Massachusetts Institute of Technology for the many courtesies extended to us in providing facilities for the holding of our meeting in this city.

The motion was carried, and the meeting then adjourned.

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Vol. V, 1887-8.

On Electric Street Cars, with Special Reference to Methods of Gearing. Anthony Reckenzaun, of London. No. 1, October, 1887—A Coulomb Meter, or Instrument for Measuring the Consumption of Electricity. (Illustrated.) Prof. George Forbes, F.R.S., of London. No. 2, November, 1887—Recent Improvements in Apparatus for Ocean Cabling. (Illustrated.) Charles Cuttriss. Supplementary Note on the Siphon Recorder, and Ocean Telephony, by Thos D. Lockwood. No 3, December, 1887—Phenomena of Retardation in the Induction Coil. (Illustrated.) William Stanley, Jr. No. 4, January, 1888.—Revision of the Patent Law. Arthur Steuart, Esq. No. 5, February, 1888.—Electric Energy from Carbon Without Heat. Willard E. Case, Auburn, N. Y. No. 6, March, 1888.—Alternating Current Electric Motors. Dr. Louis Duncan, Baltimore, Md. No. 7, April, 1888.—Maximum Efficiency of Incandescent Lamps. (Illustrated.) John W. Howell. No. 8, May, 1888.—Protection of the Human Body from Dangerous Currents. Patrick B. Delany.—The Possibilities and Limitations of Chemical Generators of Electricity. Francis B. Crocker. No. 9, June, 1888—On Compensated Resistance Standards. (Illustrated:) Edward L. Nichols. A New System of Alternate Current Motors and Transformers. (Illustrated.) Nikola Tesla. Underground Electrical Conductors in Europe and America. Prof. G. W. Plympton. The Patent Court and Uniformity in Patent Office Practice. George H. Stockbridge. A Swinging Arm Galvanometer. (Illustrated.) George S. Moler. No. 10, July, 1888. The Solution of the Municipal Rapid Transit Problem. (Illustrated.) Frank J. Sprague. No. 11, August, 1888. Some objections to the Overhead Conductor for Electric Railways, M. B. Leonard. Note on Gearing for Electric Railway Motors, Almon Robinson. No. 12, September, 1888.

Vol. VI, 1889.

[Including October, November and December, 1888.]

The Geyer-Bristol Meter for Direct and Alternating Currents. [Illustrated.] Prof. William E. Geyer. The Abdank Magnetic Call and the Abdank Integraph. [Illustrated.] E. Abdank-Abakanowicz. No. 1, January, 1889. Six Years Practical Experience with the Edison Chemical Meter. (Illustrated.) W. J. Jenks. No. 2, February, 1889. Lightning Arresters and the Photographic Study of Self-Induction. (Illustrated.) E. G. Acheson. No. 3, March, 1889. A New System of Multiplex Telegraphy. (Illustrated.) Lieut. F. Jarvis Patten. Lightning Arresters and the Photographic Study of Self Induction. Notes by Jo. Stanford Brown and Chas. T. Child. Reply to the Notes of Messrs. Brown and Child by E. G. Acheson. No. 4, April, 1889. The Efficiency of Methods of Artificial Illumination. Illustrated. Edward L. Nichols. No. 5, May, 1889. Some Results with Secondary Batteries in Train Lighting. (Illustrated.) Alexander S. Brown. The Inherent Defects of Lead Storage Batteries. (Illustrated.) Dr. Louis Duncan. Electric Motor Regulation. (Illustrated.) Francis B. Crocker. Nos. 6 and 7, June and July 1889, (Double Number). Magnetism in its Relation to Induced Electromotive Force and Current. (Illustrated.) Prof. Elihu Thomson of Lynn, Mass. On the Relation between the Initial and the Average Efficiency of Incandescent Lamps. (Illustrated.) W. H. Peirce of New York. The Efficiency of the Arc Lamp. (Illustrated.) H. Nakano, of Japan, with an introductory note by Prof. E. L. Nichols. The Spiral Coil Voltameter. (Illustrated.) Harris J. Ryan, of Ithaca, N. Y. The Personal Error in Photometry. (Illustrated). Prof. Edward L. Nichols, of Ithaca, N. Y. On Modern Views with Respect to Electric Currents. (Illustrated.) Prof. Henry A. Rowland, of Baltimore. Md. Classified List of Members. Nos. 8 and 9, August and September, 1889, (Double Number.) No. 10, October, 1889. Some Recent Electrical Work on the Elevated Railroads. (Illustrated.) Leo Daft, of Plainfield, N. J. Alternating Current Motors: The Evolution of a New Type. (Illustrated.) Lieut F. Jarvis Patten, of New York. No. 11, November, 1889. Electrical Notes of a Trans-Atlantic Trip. Thomas D. Lockwood, of Boston, Mass. Some Methods of Regulating Accumulators in Electric Lighting. (Illustrated.) George B. Prescott, Jr., of New York. No 12, December, 1889. Form and Efficiency of Incandescent Filaments. Charles J. Reed of New York. Telegraph Line Adjustment:—Note on a New Gravity Cell. P. B. Delany of New York.

Vol. VII. 1890.

Transformers. (Illustrated.) Harris J. Ryan. No. 1. January, 1890. A Review of the Modern Theories of Electricity. (Illustrated.) Prof. W. A. Anthony. No. 2. February, 1890. The Practical Working of the Electrical Subways of New York City. (Illustrated.) William Maver, Jr. No. 3, March, 1890. Some Tests on the Efficiency of Alternating Current Apparatus. (Illustrated.) Dr. Louis Duncan and W. F. C. Hasson. No. 4, April, 1890. Phenomena of Alternating Current Induction. (Illustrated.) Prof. Elihu Thomson. Electricity in the Navy. Gilbert Wilkes, No. 5, May, 1890. Electric Lighting in the Tropics. Wilfrid H. Fleming. Life and Efficiency of Arc Light Carbons. (Illustrated.) Louis B. Marks. Practical Aspects of the Alternating Current Theory. M. I. Pupin. Magnetic Data of the Sprague Street Car Motor. (Illustrated.) H. F. Parshall. The Industrial Utilization of the Counter Electromotive Force of Self-Induction. Thomas D. Lockwood. Nos. 6 and 7, June and July. (Double Number.) Life and Efficiency of Arc Light Carbons Discussion. (Illustrated.) Practical Aspects of the Alternating Current Theory. Discussion. Note on a New Photometer. (Illustrated.) Dr. Edward L. Nichols of Ithaca, N. Y. The Limitations of Steam and Electric Transportation. (Illustrated.) Oscar T. Crosby, now of New Orleans. Automatic Electric Welding Machines. Hermann Lemp, Jr., of Lynn, Mass.

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